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National Bureau of Standards, A. V. Astin, Director

Protection Against Radiations From Radium, Cobalt-60, and Cesium-137

National Bureau of Standards Handbook 54

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Preface

The Advisory Committee on X-ray and Radium Protection was formed in 1929 upon the recommendation of the International Commission on Radiological Protection, under the sponsorship of the National Bureau of Standards, and with the cooperation of the leading radiological organizations. The small committee functioned effectively until the advent of atomic energy, which introduced a large number of new and serious problems in the field of radiation protection.

At a meeting of this comittee in December 1946, the representatives of the various participating organizations agree that the problems in radiation protection had become so manifold that the committee should enlarge its scope and membership and should appropriately change its title to be more inclusive. Accordingly at that time the name of the committee was changed to the National Committee on Radiation Protection. At the same time, the number of participating organizations was increased and the total membership considerably enlarged. In order to distribute the work load, nine working subcommittees have been established, as listed below. Each of these subcommittees is charged with the responsibility of preparing recommendations in its particular field. The reports of the subcommittees are approved by the main committee before publication.

The following parent organizations and individuals comprise the main committee:

American College of Radiology: R. H. Chamberlain and G. C. Henny.
American Medical Association: P. C. Hodges.
American Radium Society: E. H. Quimby and T. P. Eberhard.
American Roentgen Ray Society: R. R. Newell and J. L. Weatherwax.
National Bureau of Standards: L. S. Taylor, Chairman, and M. S. Norloff, Secretary.
National Electrical Manufacturers Association: E. D. Trout.
Radiological Society of North America: G. Failla and R. S. Stone.
U. S. Air Force: S. E. Lifton, Maj.
U. S. Army: J. P. Cooney, Brig. Gen.
U. S. Atomic Energy Commission: K. Z. Morgan and J. C. Bugher.
U. S. Navy: C. F. Behrens, Rear Adm.
U. S. Public Health Service: H. L. Andrews and E. G. Williams.
Representatives-at-large: Shields Warren and H. B. Williams.

The following are the subcommittees and their chairmen:

Subcommittee 1. Permissible Dose from External Sources, G. Failla.
Subcommittee 2. Permissible Internal Dose, K. Z. Morgan.
Subcommittee 3. X-rays up to Two Million Volts, H. O. Wyckoff.

Subcommittee 4. Heavy Particles (Neutrons, Protons, and Heavier). D. Cowie.
Subcommittee 5. Electrons, Gamma Rays, and X-rays Above Two Million Volts, H. W. Koch.
Subcommittee 6. Handling of Radioactive Isotopes and Fission Products, H. M. Parker.
Subcommittee 7. Monitoring Methods and Instruments, H. L. Andrews.
Subcommittee 8. Waste Disposal and Decontamination, J. H. Jensen.
Subcommittee 9. Protection Against Radiations from Radium, Cobalt-60, and Cesium-137 Encapsulated Sources, C. B. Braestrup.

With the increasing use of radioactive isotopes by industry, the medical profession, and research laboratories, it is essential that certain minimal precautions be taken to protect the user and the public. The recommendations contained in this Handbook represent what is believed to be the best available opinions on the subject as of this date. As our experience with radioisotopes broadens, we shall undoubtedly be able to improve and strengthen the recommendations given in this report. In the meantime comments and suggestions will be welcomed by the committee.

This Handbook was prepared by the Subcommittee on Protection Against Radiations from Radium, Cobalt-60, and Cesium-137 Encapsulated Sources. Its membership is as follows:

C. B. Braestrup, Chairman.
H. Blatz.
M. Brucer.
T. I. Davenport.
T. P. Eberhard.
G. Ferlazzo.
E. H. Quimby.
E. L. Saenger.
H. O. Wyckoff.

A. V. Astin, *Director.*

Contents

Protection Against Radiations from Radium, Cobalt-60, and Cesium-137

1. Definitions

Terms in this report will be used in accordance with the following brief definitions:[1]

Shall denotes that the ensuing recommendation is necessary or essential to meet the currently accepted standards of protection.

Should indicates advisory recommendations that are to be applied when practicable.

Activity. See *radioactivity.*

Alpha rays, or particles. Particles emitted during radioactive disintegration, having a mass number 4 and atomic number 2. They are thus identical with nuclei of ordinary helium atoms.

Attenuation. A decrease in dose rate in passing through a material.

Background radiation. Radiation arising from radioactive material other than the one directly under consideration. Background radiation due to cosmic rays and natural radioactivity is always present. There may also be background radiation due to the presence of radioactive substance in other parts of the building, in the building material itself, etc.

Beta particles (beta rays). Electrons, positive or negative, emitted during radioactive disintegration.

Contamination (radioactive). Deposition of radioactive material in any place where it is not desired, and particularly in any place where its presence can be harmful. The harm may be in vitiating the validity of an experiment or a procedure, or in actually being a source of danger to persons.

Curiage. The number of curies (kilocuries, millicuries, microcuries).

[1] For more critical definitions, see "Glossary of Terms in Nuclear Science and Technology," National Research Council (Published by The American Society of Mechanical Engineers, 29 West 39th Street, New York 18, N. Y.).

Curie (c). A unit of radioactivity defined as the quantity of any radioactive nuclide in which the number of disintegrations per second is 3.700×10^{10}.

Daily. During each 24-hr period.

Danger range. Distance from a source of radioactive material at which the gamma radiation is 6.25 mr/hr (0.00625 r/hr).

$$\text{D. R. (cm)} = \sqrt{\frac{I\gamma \times \text{mc}}{0.00625}}$$

See definition of $I\gamma$. (6.25 mr/hr corresponds to 300 mr for a 48-hr week.)

Danger range, specific. Danger range in centimeters for an unshielded point source of 1 mc of a given radioactive substance.

Decay, radioactive. Spontaneous change of a nucleus with emission of a particle or a photon; rate of decay is usually expressed in terms of *half life*.

Dose. The quantity of radiation delivered to a specified mass or volume. Dose units are: the roentgen (r) for gamma rays, the rad for gamma and beta rays. In radiology the dose may be specified in air, on the skin, or at some depth beneath its surface; no statement of dose is complete without specification of location at which the dose is considered. Unless otherwise specified, in this Handbook dose refers to the dose in air, measured without backscatter.

Dose rate. Dose per unit time.

Dose-rate meter. Instrument for measuring dose rate.

Dosimeter. Instrument for measuring total dose.

Exposure. See *dose* (measured in air, without backscatter).

Film badge. An appropriately packaged photographic film for detecting radiation received by persons. It is usually dental-film size, and worn or carried on the person.

Gamma rays. Electromagnetic radiation of short wavelength and correspondingly high frequency, emitted by nuclei in the course of radioactive decay.

Geometry. Relative arrangement of source and measuring system.

Half life, radioactive. Time for the activity of any particular radioisotope to be reduced to half its initial value.

Half-value layer (HVL). Thickness of an absorber required to reduce a beam of radiation to one-half its incident dose rate.

Hazard, radiation. See *radiation hazard*.

$I\gamma$. Roentgens per millicurie-hour at 1 cm from an un-

shielded point source of any particular gamma-emitting radioisotope.

Isotope. One of several different atoms of a particular element, having the same number of protons in their nuclei, and hence having the same atomic number, but differing in the number of neutrons and hence in the mass number.

Lead equivalent. Thickness of lead affording the same reduction in dose rate as the material in question, under specified conditions.

Leakage radiation. See *radiation.*

Maximum permissible dose (MPD). Dose of ionizing radiation that, in the light of present knowledge, is not expected to cause detectable bodily injury to a person at any time during his lifetime.

Microcurie (μc). One-millionth of a curie (3.700×10^4 disintegrations per second).

Millicurie (mc). One-thousandth of a curie (3.700×10^7 disintegrations per second).

Million electron volts (Mev). Energy equal to that acquired by a particle with one electronic charge in passing through a potential difference of one million volts (one Mv).

Millirad (mrad). One-thousandth of a rad (0.001 rad).

Milliroentgen (mr). One-thousandth of a roentgen (0.001 r).

Monitoring. Periodic or continuous determination of the dose rate in an occupied region or of the dose received by a person.

Occupied space. Space that may be occupied by persons, or radiation-sensitive materials and devices, during the time that radioactive materials are in the vicinity.

Pocket chamber. A pocket-sized condenser ionization chamber used for monitoring radiation dose received by persons. An auxiliary charging and reading device is usually necessary.

Pocket dosimeter. A pocket-sized ionization instrument by means of which quantity of radiation is directly indicated. It is used for monitoring radiation dose received by persons. An auxiliary charging device is usually necessary.

Protection. Provisions designed to reduce exposure of persons to radiation. For external radiation, this consists in the use of protective barriers of radiation-absorbing material, in insuring adequate distances from the radiation sources, in reducing exposure time, or in combinations of these. For internal sources, it involves measures to restrict inhalation, ingestion, or other modes of entry of radioactive materials into the body. (See sections 2.2 and 9.)

Protection survey. Evaluation of the radiation hazards

incidental to the production, use, or presence of radioactive materials or other sources of radiation under a specific set of conditions. Such evaluation customarily includes a physical survey of the disposition of materials and equipment and measurements of the dose rates of radiation that may be involved. (See section 7.)

Protective barrier. Barrier of radiation-absorbing material, such as lead, concrete, etc., used to reduce radiation hazards. (See section 2.3.) *Primary protective barrier*. Barrier sufficient to reduce the useful beam to the maximum permissible weekly dose. *Secondary protective barrier*. Barrier sufficient to reduce the stray radiation to the maximum permissible weekly dose.

Qualified expert. A person having the knowledge and training needed to measure radiations and to advise regarding radiation hazards.

Rad. The unit of absorbed dose, which is 100 ergs/g. The rad is a measure of the energy imparted to matter by ionizing particles per unit mass of irradiated material at the place of interest. It is a unit that was recommended and adopted by the International Commission on Radiological Units at the Seventh International Congress of Radiology, Copenhagen, July 1953.

Radiation. Energy propagated through space. As commonly employed in radiology, the term refers to two kinds of ionizing radiation: (1) Electromagnetic waves (X-rays, gamma-rays), and (2) corpuscular emissions from radioactive substances or other sources (alpha and beta particles, etc.). *Primary radiation*. Radiation coming directly from the source, including *useful beam* (that part of the primary radiation that passes through the aperture or collimator of the radiation source enclosure) and *leakage* (*direct*) *radiation* (all radiation coming from the source, except the useful beam). *Scattered radiation*. Radiation that, during passage through material, has been deviated in direction and usually has also had its energy diminished. *Secondary radiation*. Radiation emitted by any irradiated material. *Stray radiation*. Radiation not serving any useful purpose; includes leakage and scattered radiation.

Radioactivity. Disintegration of unstable atomic nuclei by the emission of radiation, with a definite half-life.

Radioisotope. A radioactive isotope.

Radiation hazard. Any possible condition that might result in exposure of persons to radiation in excess of the maximum permissible dose. (See section 2.2.)

Radiation survey. See *protection survey*.

Radiological safety officer. Person responsible for radio-

logical safety in connection with use, handling, and storage of radioactive materials. It is his duty to make certain that all procedures are carried out in compliance with established rules, including regulations contained in this Handbook.

Rhm. Roentgens per hour at one meter.

Roentgen (r). The quantity of X- or gamma radiation such that the associated corpuscular emission per 0.001293 g of air produces, in air, ions carrying 1 esu of quantity of electricity of either sign.

Rep (roentgen equivalent physical). The quantity of any ionizing radiation such that the energy imparted to soft tissue by the ionizing particles is 93 ergs/g. (Superseded by *rad.*)

Source. Discrete encapsulated amount of radioactive material.

Source housing. Enclosure of radiation-absorbing material, used in teletherapy equipment to reduce leakage radiation to the specified level.

Survey meter. Any instrument for making a protection survey.

Teletherapy. Therapeutic irradiation with collimated gamma rays.

Useful beam. See *radiation.*

2. General Considerations

2.1. Scope

The increased applications of radium sources and the change in the maximum permissible dose have made necessary a revision of the radium protection code of the National Committee on Radiation Protection, National Bureau of Standards Handbook 23. Furthermore, the nuclear reactor has produced other high-energy, relatively long-lived, gamma emitters that are being used or may be used for similar applications. At the same time, radon plants have become rare.

The enlarged scope of the present Handbook thus deals with protection against radium, cobalt-60, and cesium-137. However, the general principles outlined for these sources will also be applicable to other gamma emitters as they become available and attenuation data are obtained for them. No specific references are made to industrial applications, since these are to be treated in a separate code; however, the basic principles and the attenuation data of this Handbook are applicable to both medical and industrial uses.

2.2. Hazards

2.21. Hazards to be considered in the use and storage of radium and other radioactive substances may be classified as:

(a) Those harmful to human beings (either engaged in work with the radioactive substance or simply staying near it).

(1) Radiation originating outside the body.

(2) Radiation originating inside the body.

(b) Those that interfere with functioning of equipment, or damage to material sensitive to radiation (photographic films).

(1) Contamination.

(2) Increase of background.

2.22. Injury to human beings may result from overexposure to beta and gamma rays from external radiation sources, from radioactive contamination of the skin by spilled material, or from accidental ingestion or inhalation of these substances.

Overexposure may occur either from working with radioactive materials under unsuitable conditions, or from habitual occupation of a position too close to the material in inadequately shielded storage. In the former case, the injury is likely to be local on the fingers and hands; in the latter it will probably be systemic.

Habitual or long-continued overexposure to the hands may result in dry reddened skin, which cracks easily and is very sensitive to heat and cold. The nails become brittle, keratoses form near them, small cracks may ulcerate. These ulcers, or any other sores, heal slowly. Cancer may develop in the keratoses or ulcers. (Of course, all exposure to radiation should be stopped long before this stage is reached.) Overexposure of the entire body may lead to depression of bone marrow activity or leukemia. The occurrence of permanent sterility is extremely unlikely.

Contamination of the skin by intimate contact with radioactive material may produce a local reaction sufficiently intense to result in erythema and desquamation. The local effect would be due mainly to beta radiation, and healing would be expected to occur without sequelae if prompt measures were taken to remove as much of the material as possible. However, repeated contamination of this type might well lead to irreversible damage.

Ingestion, inhalation, or absorption of the material gives rise first to whole-body irradiation; followed by prolonged local irradiation if a long-lived substance is deposited in a

particular region, as in the bones. Radium, mesothorium, and possibly other alpha-particle emitters are most dangerous, because of the very intense local irradiation to their preferential sites of deposit, as for example to bone or lung. Some isotopes that are not alpha-emitters are also "bone-seekers," and not well eliminated. The result is that even a small quantity of these materials, retained in the body, may lead to depression of bone marrow activity, and to serious bone lesions. Other isotopes are much more readily eliminated and do not constitute so great a hazard. Inhalation of radon from damaged radium containers may result in the deposit within the body of the decay products of the radon.

Permissible external radiation levels for long-term *occupational* exposure and for occasional exposure are discussed in detail in the report of the Subcommittee on Permissible Dose from External Sources. This report will be published as National Bureau of Standards Handbook 59.

For the limited scope of the present Handbook, the following rules based on the aforementioned report are applicable:

(a) For adults under 45 years of age, whose entire body, or major portion thereof, is exposed solely to X- or gamma rays from external sources for an indefinite period of years; the maximum permissible total weekly dose shall be 300 mr measured in air at the point of highest weekly dose in the region occupied by the person. For persons 45 years of age or older, similarly exposed, the corresponding maximum permissible total weekly dose shall be double the above stated value.

(b) For adults of any age whose hands and forearms (or feet and ankles) are exposed solely to X- or gamma rays from external sources, for an indefinite period of years, the maximum permissible weekly dose to these regions shall be 1,500 mr in the skin.

(c) For adults of any age whose entire body, or major portion thereof, is exposed to ionizing radiation of a very low penetrating power (half-value layer of less than 1 mm of soft tissue) from external sources for an indefinite period of years; the maximum permissible total weekly dose in the skin shall be 1,500 mrem, provided that the total weekly dose in the lenses of the eyes does not exceed 300 mrem.[2]

(d) It is recommended that in cases in which minors may be exposed nonoccupationally to radiation in the course of their normal activities, protective measures be taken to

[2] Number of millirems is equal to number of millirads multiplied by the relative biological effectiveness. RBE is equal to 20 for alpha rays and 1 for X-rays, gamma rays, and electrons.

make sure that no minor receives more than 1.5 r/year. Allowances may be made for the portion of the time during the week that the minors in question are not in the radiation field, and averaging of the weekly dose over a period of 1 year is permissible.

Note: Because the exposure of minors may be averaged over a whole year, the methods of computation outlined in this Handbook will be adequate for their protection in most cases, except possibly where sources are kept in residential buildings.

Permissible internal radiation levels are discussed in National Bureau of Standards Handbook 52 [15] [3] of the Subcommittee dealing with this subject. The maximum permissible amounts in the body of the elements considered in the present Handbook are: radium, 0.1 μc; cobalt-60, 3μc; cesium-137, 90 μc.

2.23. Permissible dose shall apply to the *total* dose to which a person is exposed throughout the week. This is an important consideration in cases of simultaneous and separate exposures to more than one source of ionizing radiation.

2.24. The presence of undesired radiation may interfere with functioning of equipment. If radiation reaches X-ray or photographic films, it may render them partially or totally useless. In the vicinity of ionization chambers and geiger counters it may raise the background to such a high level that satisfactory operation is impossible. Contamination of these instruments by spilled radioactive material may render them permanently useless.

2.3. Basic Principles of Radiation Protection

2.31. The ultimate purpose of all radiation-protection measures is to maintain the dose received by persons at no more than the applicable maximum permissible levels, and to prevent damage or impairment of function of radiation-sensitive films, other objects, and instruments. The dose received by persons may be reduced by any one, or a combination, of the following factors: (a) increasing the working distance from the source of radiation, (b) reducing the time of exposure, and (c) interposing attenuating (protective) barriers between the source of radiation and persons. The first of the *fundamental factors*, the distance, includes the inverse square law [4] and to a lesser extent the reduction due

[3] Figures in brackets indicate the literature references listed in section 10.
[4] The statement that the dose rate from a source varies as the inverse square of the distance from the source assumes that the absorption of the intervening medium is negligible and that the source dimensions are small (for practical purposes, one-fifth the distance).

to the air absorption. The air absorption is small for gamma radiations considered here but is very large for particulate radiation (see table 1 in appendix C).

2.32. Table 1 in appendix C shows the types and energies of radiations emitted by the sources considered in this Handbook together with the ranges of the particulate radiations. Because of the short ranges of alpha particles, no protection is required against them when the source remains intact.[5] While beta particles have considerably longer paths in air than alpha particles, they are easily stopped by thin layers of metal or plastic.[6] Usually such a layer is incorporated in the capsule sealing the source. Protection against gamma rays, because of their much greater penetration, requires more detailed consideration and the barriers required are much more expensive.

2.33. The computation of the gamma shielding requirements may be simplified by considering separately: (a) the useful beam, (b) the radiation transmitted through the source shield (leakage radiation), and (c) the scattered radiation.

2.34. *Useful beam.* The primary-protective-barrier thickness may be obtained from figures 5, 6, and 7 if the permissible transmission of radiation is known.

The permissible transmission, B, may be calculated from

$$B=\frac{0.3D^2}{WT}, \tag{1}$$

where 0.3 is the maximum permissible weekly exposure in roentgens; D is distance from source to position in question in meters; W is total weekly exposure in the useful beam at 1 m from the source (obtained by multiplying the roentgens per minute at 1 m by the weekly irradiation time in minutes); and T is occupancy factor, the fraction of weekly irradiation time during which a person is exposed (see table 2).

2.35 *Leakage radiation.* Equation (1) may be used to compute the barrier requirements for this radiation, where W is the leakage radiation in roentgens per week measured at 1 m from the source.

2.36. *Scattered radiation.* Radiation scattered from an irradiated object has a lower dose rate and is softer (of lower energy) than the incident beam. Both the energy and dose rate of the scattered beam vary with the angle of scattering.

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[5] See section 2.22, for permissible concentration in body.
[6] Some materials such as certain types of glass and plastic deteriorate under the action of particulate radiation.

However, for moderate sized fields and scattering angles greater than 90 deg, it has been shown [1] that the dose rate of the scattered radiation (measured at 1 m from the scatterer) is less than 0.1 percent of the weekly exposure at 1 m from the source for most practical cases. The barrier required for 90-deg-scattered radiation may be obtained from figures 8 and 9 if the permissible transmission of radiation by the barrier is known. The permissible transmission, B_s, may be calculated from

$$B_s = \frac{0.3S^2}{0.001\,WT}, \text{ or } \frac{300S^2}{WT}, \tag{2}$$

where 0.3 is the maximum permissible weekly exposure in roentgens; S is distance from scatterer to position in question in meters; W is total weekly exposure in the useful beam at 1 m from the source (obtained by multiplying the roentgens per minute at 1 m by the weekly irradiation time in minutes); and T is occupancy factor, the fraction of weekly irradiation time during which a person is exposed (see table 2).

2.37. *Secondary protective barriers.* The rules given above for scattered radiation and for leakage radiation may be used to compute the secondary-protective-barrier thickness for each of the two separate effects. If the barrier thicknesses so computed separately are nearly equal (that is, differ by less than 3 HVL), then 1 HVL should be added to the larger single-barrier thickness to obtain the required total.[7] But if one of the thicknesses is more than 3 HVL greater than the other, the thicker one alone is adequate.[8]

2.38. *Shielding.* If the shielding is adequate for the useful radiation it is also sufficient for leakage and scattered radiation. It should be determined, however, that radiation scattered around the end of the primary protective barrier does not cause a radiation hazard.

For reasons of economy, barriers should be placed as near to the source as possible. The barrier thickness is not reduced by this procedure but the area and therefore the volume are reduced; the barrier weight is approximately proportional to the square of the distance between the source and barrier.

Concrete, marble, and similar materials gene·ally provide

[7] Each of the two effects thus produce a permissible dose. Together they produce twice the permissible dose. This radiation can be reduced to the permissible level by the addition of 1 HVL.

[8] The larger thickness will permit transmission of the permissible level from one effect. plus not more than one-eighth (3 HVL) of the permissible level from the other effect. This one-eighth excess is negligible in view of other conservative approximations that are involved.

the most economical barrier but lead may be required where the space is limited or where it is desirable to reduce the weight.

All openings in barriers such as for doors, windows, pipes, etc., shall be provided with at least the radiation protection required for the surrounding barrier.

Joints between the same or different kinds of protective material shall be so constructed as to provide the same protection as that required of the adjacent material.

3. Equipment and Facilities for Handling, Storage, and Transportation

The equipment and facilities discussed in this section refer only to sources of intermediate curiage. Microcurie and kilocurie sources are excluded.

3.1. Handling Equipment

Radiation hazards can be significantly reduced by the proper use of suitable facilities. These facilities shall be designed to permit the necessary operations to be carried *out at considerable distance from* the source, expeditiously, and, whenever advantageous and practicable, behind protective barriers; distance, time, and shielding being properly adjusted with respect to the influence of one upon the others. The effects of distance, time, and barriers are discussed in section 2.

Sources should never be touched with the hands. There should always be some distance between sources and the operator. In hospitals and laboratories where sources are employed, suitable facilities shall be provided to insure safe handling.

3.11. *Forceps.* Forceps for handling sources or applicators incorporating sources should have the following general characteristics:

(a) They should be as long as practicable and should grip the source or applicator firmly with a minimum of force exerted by the fingers.

(b) Spring-operated self-clamping forceps are desirable where practicable.

(c) The jaws should be notched, grooved, or otherwise formed to fit the applicators to be handled.

(d) The forceps should be light in weight to permit rapid and accurate manipulation.

(e) They should be provided with metal hand shields of ½-mm lead equivalent for the absorption of primary beta rays if present.

(f) Forceps used to lift easily damaged sources should have a "spring tip" adjusted to prevent excessive pressure. "Cross-action" forceps are desirable for some delicate manipulations.

3.12. L-*block*. The preparation and dismantling of applicators incorporating sources, or similar operations, shall be carried out behind a protective L-block of such size and thickness as will adequately shield the operator. The block should have the following general characteristics (see fig. 1):

(a) The top should be provided with an inclined high-density transparent "visor," or an alternate arrangement for viewing.

(b) The side next to the operator should have a protective pad to keep his body at least 30 cm from the point where the source is handled, or the block should be so placed on the working table as to accomplish the same result without such pad.

(c) The inside corner of the L should preferably be curved.

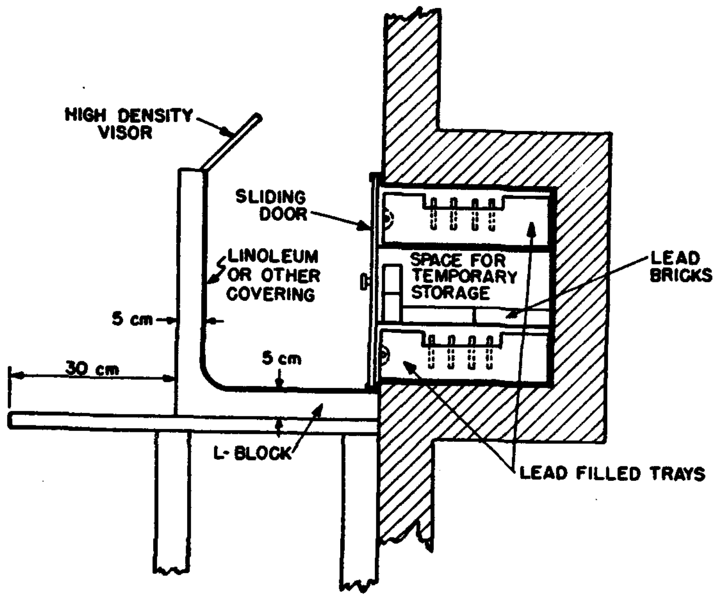

FIGURE 1. *Suggested arrangement of preparation bench with* L*-block and source storage enclosure recessed in wall.*

(d) For the usual L-block having a minimum lead equivalent of 5 cm, the following maximum weekly millicurie-hours at a distance of 30 cm are permissible: radium, 160 mc-hr; cobalt-60, 100 mc-hr; cesium-137, 360 mc-hr.

(e) A lead-lined "well" or its equivalent should be provided near the L-block, so that the required radioactive sources can be held therein during the preparation of an applicator.

Note: The maximum weekly permissible dose of 1.5 r to the unshielded hands determines the above limits. The weekly dose to the part of the body shielded by the L-block is less than one-third of the 300-mc maximum permissible dose.

3.13. *Clamping devices.* Vises, chucks, or similar arrangements should be provided at the protective L-block to facilitate preparation of applicators; preferably, these devices should be operated by foot pedal or by handle removed as far as practicable from the inside of the L-block. Their design and use should minimize the possibility of damaging the sources through excessive clamping pressure. This can be prevented by means of a spring-loaded ratchet or slipping-clutch mechanism.

3.14. *Threading devices.* A suitable device should be provided for threading needles or tubes expeditiously, with the fingers protected as much as possible by distance and barriers.

3.15. *Magnetic handling devices.* This method is applicable only if the sources are magnetic, i. e., either the radioactive material itself is magnetic, as cobalt-60, or the container of the source is magnetic. The residual magnetism of these sources should not be much higher than that of soft iron, or else it may become difficult to perform the necessary operations rapidly and accurately. If the sources become permanently magnetized to such a degree that they cling together or to any magnetic material with which they come in contact, their handling, cleaning, and storage will become difficult.

3.16. *Pneumatic devices.* Vacuum may be employed to hold sources. Also, if a controlled and definitely limited impelling pressure is employed to drive sources over a short distance, certain storage and handling operations can be performed to advantage and without undue hazard, provided that the sources contain no radioactive powder or liquid and are not subject to dusting or corrosion.

The handling normally done by means of forceps can be performed to advantage by means of properly designed

"hand-guns" with pistol-type grip and trigger operating on suction, provided that the construction and operation of the "gun" is such as to insure that the sources will not be damaged.

3.17. *Electromechanical devices.* Servo-mechanisms may be used to advantage for the selection and distribution of individual sources. Rotating storage containers have been constructed that permit remote selection and release of sources.

3.2. Storage Facilities

When not in use or in transit, sources and applicators incorporating sources shall be kept in a protective enclosure of such material and wall thickness as may be necessary to insure that no person is exposed to more than 300 mr/week.

The enclosure should be provided with means to prevent unauthorized removal of the sources.

The protective enclosure may be advantageously located near the preparation work bench to reduce the exposure of personnel during transfers of sources.

The protective enclosure should be constructed in such a way as to minimize, as much as possible, the exposure of personnel in the handling of the sources. Important factors to consider are: (a) distribution of the sources, (b) shielding of subdivided amounts, and (c) time required by personnel to remove sources from the enclosure and return them to it.

Consideration should be given to the scattered radiation. It is not sufficient to place large sources behind a barrier, no matter how thick, if the radiation scattered around it presents a hazard. Where a large number of sources are stored, a lead-lined safe with lead-filled trays may be used to advantage. This permits the individual sources to be stored in holes in the lead of the trays.

Separate compartments should be provided for different types of sources.

Each compartment should be marked so as to permit immediate and certain identification of its contents from the outside. It is highly desirable that tubes, cells, needles, etc., be readily identifiable from a considerable distance as to their type and activity. When sizes and shapes are not adequate other means should be employed.

The protection of the individual compartments and enclosures as a whole should be such that a person standing in front of the enclosure in performance of his duties receives in that time only a small fraction of the permissible dose.

3.3. Transportation Facilities

3.31. *Intramural transport carriers.* Transportation of radioactive sources within an institution should be done only by means of adequately shielded carriers. In general, lead is the most practical shielding material for carriers. Such carriers should have the following characteristics:

(a) The thickness of the lead shielding shall be such that the person transporting the carrier does not receive more than 300 mr/week. Account should be taken of the actual transport time and allowance must also be made for other possible exposure to radiation. Tables 8, 9, and 10 (appendix C) give the required thickness for various conditions.

(b) Loading and unloading should be possible with minimum exposure.

(c) Long handles should be provided to bring the source close to the floor in the normal carrying position. The design of the carrier should be such as to encourage the use of the handles. The shielding of the bottom may be less than that of the sides and top.

(d) For the transfer of large sources of shielded container with wheels may be required to permit the use of heavier shielding and to afford greater distance between source and courier.

(e) Carriers should be suitably labeled.

3.32. *Transportation by private car.*[9] [10] During transportation of radioactive sources by private car (such as by physicians in practice), the source should be in a transport carrier offering adequate shielding to all occupants of the car.

The carrier should be located as remotely as practicable from occupants. It should be suitably marked with the name and address of the owner, a notice that the contents may be dangerous if removed, and that the owner should be notified if the carrier is found.

If it is necessary to leave radioactive materials in an unattended car, the container shall be locked in the car, preferably in the luggage compartment.

Any loss or theft of radioactive material that may constitute a potential public hazard should be reported im-

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[9] An opinion of the Bureau of Motor Carriers of the Interstate Commerce Commission indicates that a "physician, in transporting in his personal car instruments and medicines usually carried by such persons in pursuing their practice, including sources of radium used for treatment, would not be a private carrier of property under the Interstate Commerce Act. That being the case, the transportation of radium under the circumstances described . . . would not be subject to the explosives and dangerous articles regulations." Private communication from the Director, Bureau of Motor Carriers (11-10-52).

[10] Tunnel and bridge authorities may regulate or prohibit the transshipment of dangerous material through vehicular tunnels and over major bridges.

mediately to the local police or public-health authorities.

3.33. *Public transport containers.* The public transportation of radioactive materials is subject to federal, state, and local regulations.

Those responsible for the shipment of sources should be familiar with the current regulations of the Interstate Commerce Commission, Post Office Department, and Civil Aeronautics Board (see appendix B, Shipping Rules).

4. Medical Applications—Interstitial, Intracavitary, and Surface

In the medical applications of radioactive sources, there are five operational stages during which radiation hazards may exist:

(a) Transfer of sources from storage and preparation for use on patients.

(b) Transfer from preparation bench and application to patient.

(c) Irradiation of patient.

(d) Removal of sources from patient and transfer to preparation bench.

(e) Removal of sources from applicators, cleaning, and transfer from preparation bench to storage space.

Each of these stages and each type of source present peculiar problems. These will be considered individually.

4.1. Transfer of Sources from Storage and Preparation for Use

There is an unavoidable minimum exposure associated with the handling of radioactive sources and the dose for a specific procedure depends largely on the skill of the operator. The beginner should, therefore, be carefully trained with dummy applicators until a high degree of competence has been attained.

These general precautions should be noted:

(a) Excessive use of over-long, too heavy, or otherwise cumbersome instruments will frequently increase the time of the operation to the point where the total exposure exceeds that obtainable with less physical protection and correspondingly less time.

(b) Lead rubber gloves are particularly objectionable because they provide insignificant protection and handicap the operator.

(c) Care should be taken not to let the worker dispense with protection simply because working without it seems to be the "easy" way. With training, great dexterity can be attained while still taking advantage of optimum physical protection.

(d) All applicators should be carefully designed for ease of handling. Needle eyes should be large enough for easy threading. Thread ends subject to fraying should be prepared with beeswax or plastic. Screw threads should be carefully cut and of optimum size and pitch to allow fast, jam-proof operation. Each type of applicator should have its special tool for the manipulation of screw caps and plugs, without the necessity of holding either the applicator or the cap or plug in the hands.

(e) All cavities in applicators into which sources are to be placed should be so designed that removal of the source, even when stuck by the accidental entrance of coagulable body fluids, can be accomplished easily and safely. All steps possible in the preparation and assembly of an applicator should be carried out before the insertion of the source.

(f) When multiple needles and capsules of the same appearance but of different strengths are used, they should be identified with different colored threads or beads at the time of loading. Further identification by the use of small numbered tags, the numbers being recorded at the time of loading, at the time of insertion, and upon removal and unloading, is added protection against mixing of the sources in the storage containers.

(g) Heat sterilization of radium or cesium sources should be avoided. As these containers age, there may be considerable accumulation of gas and water vapor, the expansion of which can easily rupture thin-walled cells. Old sources that have been heat sterilized should be tested for leakage (see section 7.5).

(h) Attention should be paid to the possible deleterious effect of some chemical sterilizers.

(i) Areas used for preparing radioactive applicators should be monitored both for exposure to workers and for contamination from faulty containers. Radium usage, of course, demands particular attention to the presence of alpha-emitting contaminants (see section 9).

4.2. Application of Sources to the Patient

At this stage, physicians and nurses who are not thoroughly experienced in these techniques are frequently involved, and the responsibility of the physician in charge is great. Certain

precautionary rules should be followed:

(a) Personnel should be allowed to do this work only after a period of training. No physicians or nurses should be engaged in this work unless they are familiar with the hazards involved and the techniques of minimizing them.

(b) All practicable physical protection should be given. Protective barriers may be mounted on small wheeled carts and provided with sterile drapes. The barriers should be so designed as to give protection in all directions where nearby persons are usually stationed during radiotherapeutic procedures. Frequently, little or none of this is practicable during some part of the procedure. In that case, distance and speed are to be stressed.

(c) *Physicians should neither order nor permit nurses or other persons to pick up sources with their hands.* Proper handling instruments should be provided and their use strictly enforced.

4.3. Precautions While Source is in or on the Patient

4.31. The bed, cubicle, or room of the hospital patient should be marked with a tag or sign stating what radioactive substance is being used, the number and nature of the sources, the total amount of material, the time and date of application and anticipated removal, instructions to nurses, and any remarks that would enable the source custodian to retrieve sources. If the curiage of the sources is so dangerously large that occupancy of surrounding areas should be restricted, a special tag should indicate the danger range to discourage persons from remaining in the area unnecessarily.

4.32. The extent to which the patient with radioactive material must be segregated depends upon the type of source and the total curiage, its location on the patient, how long it is to be on him, how long his neighbors stay near him per week, and to what other exposure those neighbors (patients or nurses) are subject. Table 7 (appendix C) gives the distances for various millicurie-hours of radium, cobalt-60, and cesium-137 at which a person will receive the maximum permissible weekly exposure of 0.3 r.

4.33. Patients with removable sources in or upon their persons should not be permitted to leave the hospital or clinic.

4.4. Removal of Sources from Patient and Transfer to Preparation Bench

4.41. The same safety precautions observed at time of insertion should be observed at time of removal, and all sources shall be accounted for.

4.42. Precautions should be taken during cleaning of applicators to prevent their damage or loss in plumbing systems.

4.5. Removal of Sources from Applicators

Any dismantling of an applicator shall be limited to the removal of the source from the applicator. The removal of the radioactive material from a source should be done only by those persons particularly trained and equipped to do the job.

4.6. Records

In every hospital or clinic stocking sources there shall be a custodian of sources. This custodian or his deputy should keep a permanent record of the issue and return of all sources. This record should include:

(a) The source order with its date, and date received.

(b) The patient, hospital and department, and physician who issued the order.

(c) Source issued: stating type and identification of appliance, total curiage, person to whom issued, signature of individual receiving the material, date and time of issue.

(d) Date of expected return, date of return of source, signature of individual certifying complete return.

The source custodian should take periodic inventories of all sources.

5. Medical Applications—Teletherapy

5.1. Radioisotopes as Sources for Teletherapy Apparatus

5.11. *Possible sources.* The radioisotopes in table 3 can be made available as teletherapy sources. They all emit gamma rays within an energy range suitable for teletherapy and have a half-life over 70 days. Most teletherapy sources can be expected to deliver between 1 and 50 r/min at a distance of 1 m. Such sources will have dose rates of many kiloroentgens per minute close to their surfaces and when not in their housings must be handled with remotely controlled instruments at great distances or behind thick bar-

riers. Apparatus containing such sources must be so designed as to be practically foolproof in operation and it must be improbable for any accidents to leave the source unshielded.

5.12. *Physical form of the source.* Some of the isotopes shown in table 3 can exist as pure solid metals and can be cast, machined, or pressed before irradiation. The metallic state is the most stable and easily handled and therefore the preferable form for any source. Solid sources are likely to consist of multiple wafers, pellets, or cylinders, which must be fitted into a container. Neutron and chemical corrosion can cause a dusting problem and the containers must be designed to prevent the release of radioactive dusts.

Some sources can exist only as powdered salts, e. g., europium oxide, the specific activity of which is very high. Before irradiation such salts can be mixed with aluminum powder and pressed into metallic discs to reduce the hazard of working with powdered sources. Some materials, such as cesium sulfate, have too low a specific activity to be mixed with aluminum but can be pressed to high density within their containers to reduce the hazards of the powdered form. Such containers should be doubly protected against leakage. Some isotopes might conceivably be used in a loose powdered form, or could be produced in a liquid form. Containers for loose powders or liquids must be specially designed to prevent accidental release of the material.

5.13. *Preparation of pure metallic sources.* Certain sources e. g., cobalt-60 and iridium-192, can be prepared as metals or metallic alloys of high purity. Such sources shall be sealed in air-tight capsules of stainless steel or other suitable material. One recommended design and method of sealing is shown in figure 2.

5.14. *Testing of metallic sources before use.* After the isotope is loaded into its permanent capsule, the capsule shall be scrubbed clean of contaminating radioactivity. It shall not be released by the manufacturer until a reasonable test

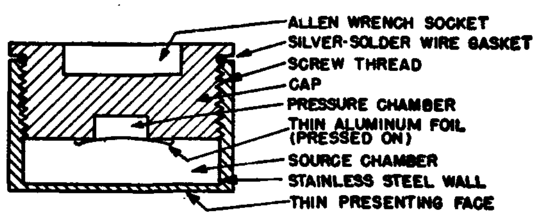

FIGURE 2. *Air-tight single capsule for sources of small curiage.*

reveals no significant contamination. A recommended test is to scrub the dry capsule with a dry filter-paper sponge and to count the activity on the paper under standardized geometry.

5.15. *Preparation of powdered sources.* Radioactive isotopes of certain elements such as cesium, europium, and radium are not made in pure metallic form. Usually the oxides or sulfates are used. It is desirable to use a compound that yields the highest volume specific activity but it is necessary that such characteristics as deliquescence, decomposition, and gas production in a high gamma radiation flux be taken into consideration.

5.16. *Source capsules.* Isotopes used in teletherapy shall not be sealed in glass or other breakable containers. Quantities of a few curies can be sealed in airtight source holders as suggested in figure 2. Large sources have very high internal gamma intensities and are subject to decomposition of salts and minor contaminants, appreciable heat generation, and the potential production of gases, with a build-up of pressure within the source container. Such sources should be sealed in a source container and the re-sealed in a second safety capsule containing an air pocket as suggested in figure 3.

A standard source capsule for high curiage teletherapy has been developed and accepted by the Canadian and U. S. producers of cobalt-60 as well as by the manufacturers of teletherapy equipment. Its design is shown in figure 4. Detailed information is available from the Medical Division, Oak Ridge Institute of Nuclear Studies, Oak Ridge, Tennessee.

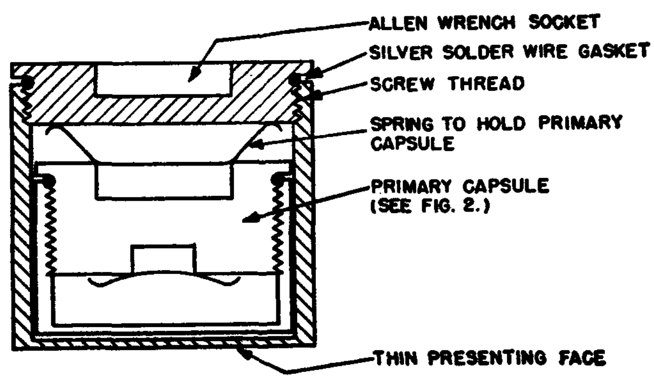

FIGURE 3. *Air-tight double capsule for sources of large curiage.*

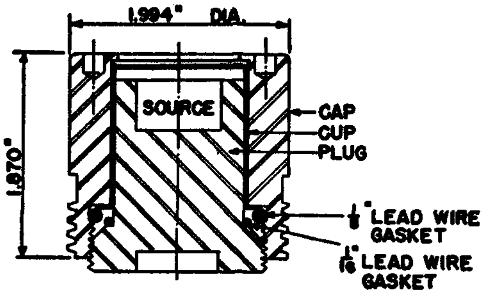

FIGURE 4. *Standardized source capsule.*

5.17. *Testing of powdered sources before use.* The manufacturer shall decontaminate and test the primary powdered-source container. The outside of the secondary container shall be free from significant contamination.

5.2. Design of the Teletherapy Apparatus

Teletherapy apparatus may be divided into two types: single-source and multiple-source equipments [2].

5.21. *Single-source units.* Single-source units consist of at least three parts: a completely shielded housing adequate for the source in the "off" position, a collimating aperture, and a device to turn the beam "on" and "off". The housing may be of cast metal or of machined or sintered metals. There will be, of necessity, ports in the shield to allow for loading and opening devices.

5.22. *Multiple-source units.* Multiple-source units may be of many diverse designs. Where sources exist as separate units, each should meet the protection requirements of a single-source unit, except that the protection requirements for the entire apparatus shall in no case be less than those recommended for a single-source unit.

5.23. *Protection requirements for the housing.* The housing and collimating devices shall be so constructed that at 1 m in any direction from the source in the "off" position, the maximum and average dose-rates do not exceed 10 mr/hr and 2 mr/hr, respectively.

In order to reduce the integral dose to the patient, the leakage radiation in the "on" position should not exceed 1 percent of the useful beam both measured at 1 m from the source. A reduction of the leakage radiation to 0.1 percent

or lower will result in a more economical secondary protective barrier.

5.24. *Protection requirements for the collimating device.* Adjustable beam-defining diaphragms shall allow transmission of not more than 5 percent of the useful-beam dose-rate outside of the useful beam.

5.25. *Filters.* Filters to harden the radiation are usually unnecessary in most teletherapy machines. In the case of some radioisotopes, for example europium-152-154, where filtration of soft gamma rays is necessary, the filter shall be a permanently affixed part of the housing.

5.26. *Positioning of the source in the housing.* The relationship of the source and the collimating opening shall be such that in the "off" position of the beam the moving part shall always return to a position of shielding as defined in section 5.23. In the "on" position the moving part shall always come to rest with the source and the beam collimating device accurately aligned. If a liquid "on-off" device is used, the liquid container shall be filled and emptied with less than a 5-percent change in dose rate in the "on" position. If the liquid is mercury; periodic tests should be made for leakage of mercury vapors, since they are toxic [3] and also may affect the film badges used in monitoring personnel.

5.27. *Beam control.* The beam-control mechanism shall be of a positive design capable of acting in any position of the housing and shall shut off automatically. In addition to the automatic closing device, the apparatus shall be so designed that it can be manually turned off with a minimum risk of exposure. The moving parts shall be so designed that it is highly improbable for projections, breakages, loose screws, dirt, or failure of any part to impede the closing of the source. There shall be at the housing and on the control panel a warning device that plainly indicates whether the apparatus is "on" or "off." The controls shall be provided with a timer that automatically terminates the exposure after a preset time.

5.28. *Precautions in the "on-off" beam-control mechanism.* Whatever the "on-off" shutter mechanism (solid, liquid, slide, wheels, or shutters), the closing device shall be so designed as to return automatically to the "off" position in the event of any breakdown or interruption of the activating force and shall stay in the "off" position when the force goes on again until activated from control. The beam control shall be provided with a locking device to prevent unauthorized use.

5.3. Design of the Teletherapy Room

In general, the requirements of teletherapy rooms are the same as those given in NBS Handbook 41, section 12, "Therapeutic X-ray Installations Energized by Potentials of 251 to 2,000 Kilovolts." The protection design for teletherapy rooms follows the same principles as stated in NBS Handbook 50, "X-ray Protection Design."

5.31. *General structural requirements*. Lead barriers shall be mounted in such a manner that they will not creep because of their own weight and shall be protected against mechanical damage. Movable barriers should not be depended upon except for emergency procedures.

Protection for the useful beam shall be computed without a patient in the beam. In general it is more economical to place the observation window so that the useful beam cannot be directed at it and to provide a maze rather than a heavy lead or steel door for access to the radiation room.

5.32. *Primary protective barriers*. Primary protective barriers shall be provided for any area that the useful beam may strike with the largest possible diaphragm opening. These barriers shall extend at least 6 in. beyond the useful beam for any possible orientation. The actual protection requirements will depend upon the type and curiage of the source and the weekly irradiation hours. The barrier shall be of such that no person outside the radiation room can receive more than 300 mr/week (see tables 4 and 6, appendix C).

In the case of most isotopes, the radiation is not a continuous spectrum but is from either single or multiple monoenergetic gamma energies. The protection requirements will be higher for a monochromatic gamma energy than for a similar peak energy from an X-ray generator.

The controls should be in a separate room or behind permanent structures. All access doors to the treatment room and other hazardous areas shall be provided with electrical interlocks; warning lights, bells, or other devices should also be provided.

5.33. *Secondary protective barriers*. Secondary protective barriers shall be provided for all areas exposed to leakage and scattered radiation. See tables 5 and 6 (appendix C) for thicknesses required.

5.4. Operating Procedures

Only the patient should be allowed in the treatment room during irradiation. At all other times the treatment room should not be occupied except as required for setting up and removing patients.

6. Nonmedical Applications

6.1. General

6.11. This section deals with all nonmedical applications within the scope of this Handbook. Specific consideration is given here to the uses of sources in instrument calibration, research, and civil-defense exercises.

6.12. In the event that a situation beyond the reasonable contemplation of these recommendations is believed to exist, any deviation shall be allowed only upon authorization by the radiological safety officer after a thorough survey of the conditions.

6.13. Labels stating type of activity, amount, and danger range, shielded and unshielded, should be attached to the source shield. Lettering should be easily read at the danger range.

6.2. Calibration Sources

6.21. Calibration sources having dose rates less than 10 mr/hr at the surface do not singly represent radiation hazards. However, precautions against escape of free radioactive materials from the source shall apply. Sources that singly do not represent radiation hazards may produce such a hazard when more than one are located in the same vicinity, as in the case of bulk storage.

6.22. Low-level sources intended for hand manipulation during the calibration of monitoring instruments shall have a surface dose rate less than 30 mr/hr assuming not more than 10-hr exposure per week.

6.23. Calibration sources permanently mounted within an instrument shall not produce more than 30 mr/hr at any surface of the instrument readily accessible during either normal operation or the performance of routine maintenance. The presence of such sources shall be clearly indicated by a suitable permanent legend on the face of the instrument stating the isotope and its curiage. The source shall be readily distinguishable upon dismantling the instrument.

6.24. Remote-handling equipment shall be used with sources exceeding 30 mr/hr at the surface. Movement of

sources from shielded position to calibration position should be accomplished by mechanical linkage or other remote-control methods. However, in the case of radium and other powder sources, only those methods of transfer are recommended that do not subject the source to repeated shocks or vibration, and that provide positive automatic safeguards against the possibility of damage to the source and spread of contamination due to malfunction of the system. A signal shall be provided to show when the source is in calibration position. The area within the danger range should be made inaccessible. Mere warning signs or signals shall not be considered sufficient unless the area is under surveillance.

6.3. Research Applications

6.31. Sources shall be subject to the provisions of sections 6.1 and 6.2 except as otherwise permitted by the radiological safety officer. Any such modifications shall not increase the exposure of persons beyond the permissible level.

6.32. It shall not be considered sufficient to calculate dose rates and danger range for multicurie sources from consideration only of the amount of activity present. For such sources an actual survey of the radiation levels should be made. Consideration must be given both to primary and scattered radiation.

6.33. Teletherapy apparatus used for research shall be subject to the same design criteria and operational precautions as those recommended in section 5 for medical teletherapy apparatus except that considerations given to the protection of the patient against accidental overexposure shall not apply where animals, plants, and other experimental materials are being irradiated. Precautions, however, should be taken by means of a door lock or alternative means to prevent unauthorized persons from entering a teletherapy room while the beam is in the "on" position. Interlocks need not be electrically operated.

6.4. Civil Defense

6.41. Civil defense uses present two special problems in field operations: (1) extremely rough usage, and (2) possible use by untrained personnel.

6.42. Such sources must be encapsulated in containers especially designed for protection against rupture when subjected to rough usage. Glass containers shall not be

used. The curiage of any source must be the minimum required for the purpose.

6.43. Permanent markings shall be provided and shall give, in addition to type and amount of activity and danger range, information concerning radiation hazards and dangers attendant upon rupture of the source containers.

7. Protection Surveys and Personnel Monitoring [11]

7.1. Protection Surveys

7.11. An initial survey should be made of any facility to be used for the handling or storage of radioactive sources covered by this Handbook. This survey should include all storage containers, transport carriers, shields, and teletherapy equipment. The survey should be made by or under the supervision of a qualified expert, who shall submit a suitable written report.

7.12. If any changes are made in the layout or shielding, or if there is a possibility of a fault developing through cold flow in metallic shielding or through wear, the survey should be repeated at appropriate intervals. Such surveys should be the basis of limiting time of occupancy of certain areas, or performance of certain duties, if necessary. Any limitation should be embodied in the procedures (section 8.2 (c)).

7.13. For conditions where the dose rate is expected to be low, films may be used in making an approximate survey. If indicated, a survey should then be made with suitable instruments (see NBS Handbook 51, section VI [4]).

7.14. Ionization-chamber measurements are required only if a prior scanning with a suitably calibrated Geiger-Mueller or scintillation type of instrument indicates occupied regions to have a radiation level of more than one-fifth of the permissible dose rate.

7.2. Storage Containers

7.21. The survey of storage facilities should be made with all the usual sources in the safe and with the safe closed. The danger range should be determined in all occupied space and indicated, if necessary, with warning signs. A survey should also be made with the safe open, as when sources are being inserted or removed, to determine the degree of hazard

[11] NBS Handbook 51 [4] covers this subject in detail. Only special problems related to the use of radium, cobalt-60, and cesium-137 are considered here.

involved in such operations. Such a survey may be made by using personnel monitoring devices or other suitable instruments.

7.3. Teletherapy

7.31. No teletherapy installation should be used routinely until its safety has been established by a protection survey. This survey should be made with the beam in the "off" position to determine that it complies with the requirements of a protective source housing (see section 5.23). Operation procedures based on such a survey should be established for all personnel concerned.

7.32. A survey should also be made of all regions adjacent to the radiation room with the beam on. A patient or phantom should be in place when scattered radiation is measured. Such measurements should be for typical useful-beam directions to determine the dose to personnel under actual conditions of operation. The report should include restrictions of operation or occupancy if indicated by the measurements.

7.33. Pinhole leaks shall be considered in terms of the possibility of a hazard to operator or patient rather than in terms of the specified exposure rates.

7.4. Warning Signs

7.41. Any restrictions in occupancy should be indicated by appropriate warning signs. The sign should be removed when the hazard is eliminated.

7.5. Radium Leakage

7.51. All radium sources should be tested for contamination upon receipt, if facilities are available. Sources certified by the National Bureau of Standards are so tested at the time of certification. If there is reason to believe that a source has been damaged, it shall be tested for leakage. If facilities are not available locally, it shall be sent to a qualified laboratory for test.[12]

7.52. To test for leakage, a Geiger-Mueller or scintillation counter or an alpha survey instrument is required. Each radium source to be tested can be placed close to or wrapped in an absorbent material such as cotton or filter paper and left for at least a day, preferably in a small sealed container. The absorbent material should then be checked for contam-

[12] The National Bureau of Standards does not accept radiation sources for such tests.

ination with a suitable instrument. The presence of contamination indicates a leak. If radium leakage is gross or has existed for some time, merely wiping the source and testing the wipe should show contamination. This is also true for cobalt-60 and cesium-137 sources.

7.53. Sources that leak shall be placed in sealed containers and can be sent to a qualified laboratory for repair and measurement. Containers and carriers, as well as any other equipment that has had contact with the leaking source, shall be decontaminated (see NBS Handbook 48 [5], section IV) under the direction of a qualified expert.

7.6. Personnel Monitoring

7.61. Personnel monitoring should be employed where the radiation safety depends upon proper operating procedures. A film badge, pocket dosimeter, or pocket chamber may be used. Various types of wrist badges, or rings incorporating either films or ionization chambers, are available for monitoring local exposure to the hands. If a particular operation is routine or repetitive and the hazard is slight, the local exposure may be established initially without the necessity of wearing such devices continuously.

8. Working Conditions

8.1. General

8.11. Before a person is allowed to handle radioactive sources he shall be informed of the hazards involved and how to guard against them. Such an employee should be required to read the sections of this Handbook pertaining to his work and any special local safety rules.

8.2. Radiological Safety Officer

8.21. In every hospital, clinic, or laboratory handling radioactive sources, there shall be a radiological safety officer. The radiological safety officer shall be responsible for the establishment of satisfactory working conditions according to current standards including those established in this Handbook.

8.22. The specific duties of the radiological safety officer or his deputy should be to:

(a) Assure that every worker selected to handle radioactive materials has suitable physical and mental require-

ments to qualify him for the work to be performed.

(b) Be responsible for the instruction of new personnel in safe working practices and in the nature of injuries resulting from overexposure to radiation.

(c) Establish and maintain operational procedures so that the radiation exposure of each worker is kept as far below the maximum permissible as is practicable.

(d) Assure that under normal conditions no one except patients receives more than the maximum permissible dose per week.

(e) Investigate each case of excessive or abnormal exposure to determine the cause and take steps to prevent its recurrence.

(f) Assure that personnel monitoring devices are used where indicated and keep permanent records of the results of such monitoring.

(g) Assure that suitable warning signs are in place when and where required.

(h) Keep records of all sources including their locations.

(i) Conduct periodic radiation surveys where indicated (see section 7) and keep records of such surveys, including description of corrective measures.

(j) Assure that all shields, containers, and handling equipment are maintained in satisfactory condition.

8.23. Any region that is easily accessible and that cannot be continuously occupied without exceeding the maximum permissible dose should be posted to warn all concerned that this is a dangerous area. This specifically applies to regions where sources are stored or handled, and areas where patients are being treated. The combination of the permissible working distance from the source and the exposure can be determined from tables 8, 9, and 10 in appendix C.

8.3. Physical Examinations

8.31. If shielding facilities and working conditions, as outlined in this Handbook, are maintained, radiation exposures should be well below those that should be expected to produce any measurable physiological effect.

8.32. No special examinations other than those considered good medical or industrial practice should be required. Preemployment physical examination is always advisable in order to reveal any physical conditions that later may be attributed to radiation exposure. The preemployment examination should include: (a) medical history, (b) radiation exposure history, (c) physical examination, and (d) blood

count. If there is any possibility of accidental heavy exposure to any person, a normal blood-count series for any such individual would be useful as a later reference to indicate radiation damage or absence of significant radiation damage.

8.33. Individuals with faulty vision that cannot be corrected properly with glasses should not be employed.

8.4. Vacations

8.41. Vacations should not be considered protection against exposure to radiation.

9. Accidents Entailing Radiation Hazards

9.1. Introduction

9.11. The escape of radium or other isotopes from sealed containers has occurred. Such accidents have created health hazards, and the cost of decontamination after such accidents has been extremely high. The causes of such accidents are often obscure. Constant vigilance is required to guard against spillage of radium and other isotopes, and also against loss of the sources.

9.12. The hazards resulting from contamination of humans and the entry of radioactive substances into the body vary greatly with various isotopes, depending on their physical and chemical properties and forms. Because the metabolism of these isotopes in humans is often not well understood, rather detailed study procedures are described in order to provide further helpful information for any accident that may occur as well as to protect exposed individuals.

9.2. Spillage

9.21. If there is reason to suspect that a disruption of a sealed source containing an isotope has occurred, the following emergency measures shall be taken at once:

(a) No immediate attempt shall be made to clean up the spill.

(b) All windows shall be closed, fans and air-conditioners shall be shut off, and everyone shall leave the room.

(c) All doors shall be closed and locked.

(d) If powdered or gaseous sources are involved, the door and all other openings leading into the room shall be sealed with wide masking tape or adhesive tape and heavy wrapping paper.

(e) Every person who might have been contaminated shall be tested for radioactivity, and, if contaminated, shall remove his clothes and be decontaminated. If no means are available for testing, it shall be assumed that the person is contaminated.

(f) Entrance to the contaminated area shall be prohibited.

(g) A consultant experienced in radiation hazards should be called in and his advice followed.

(h) In radium accidents, portable alpha meters shall be obtained so that adequate decontamination can be carried out.

(i) Special problems associated with the spillage of liquid sources are covered in NBS Handbook 48 [5].

9.22. Under no circumstances shall any untrained person attempt to examine or clean up any spilled radioactive material. (The cleanup technique should be planned with the same care as is used in quantitative chemical analysis or in bacteriological handling of extremely virulent organisms.) Fans or ventilating apparatus should not be turned on in an attempt to blow away the isotope or its decay products. Such a maneuver will only disseminate the radioactive material throughout the area. If the isotope is blown out of a building, air currents may carry the finely divided material into nearby windows or air-intake ducts. Proper precautions taken immediately will protect human life and minimize financial losses.

9.3. Emergency Care for Possibly Contaminated Persons

9.31. All suspected persons should be surveyed for radioactive contamination.

9.32. If no monitoring instrument is available, all possibly exposed persons should be regarded as contaminated. Wipes from various parts of the bodies of these persons and their clothing should be made with some type of disposable tissue, filter paper, or blotting paper, and the samples placed in separate labeled envelopes for future study.

9.33. Contaminated persons should remove all clothing carefully and place it in some type of disposable container or bag. If this is not available, clothing should be put on paper to prevent contamination of floor and furniture. This can be monitored later to determine the possibility of decontamination or the need for disposal.

9.34. Contaminated persons should then be covered with some type of emergency clothing and taken to a shower area for bathing.

9.35. Bathing should be done under showers and commercially available detergents and soaps can be used. Several separate washings should be performed. Highly alkaline soaps, abrasives, organic solvents, or cleaners that tend to increase permeability of the skin should not be used. Special emphasis should be given to cleaning of fingernails, toenails, nostrils, scalp, ears, and body folds.

9.36. Scrub brushes should be used, but care should be taken that the skin surfaces do not become abraded.

9.37. After the body is well washed, the person should be surveyed with a suitable monitoring instrument and additional smears taken with disposable tissues, cotton-tipped applicators, or filter paper. The ear canals and nostrils should be swabbed for contamination. Smear tests are especially important if alpha survey instruments are not available. Fresh clothing should be put on.

9.38. Small cuts and other breaks in the skin surface should be sought for carefully, since absorption of isotopes can occur by this route. Such lesions should be decontaminated after the above washes by repeated 5-min scrubs after removal of scabs and crusts.

9.39. A physician should be called immediately to carry out the following medical studies on contaminated persons:

(a) Complete medical history and physical examination with special emphasis on previous occupational history and possible exposure to radiation should be secured. A chest roentgenogram should be obtained.

(b) Complete blood count, including hematocrit reading, and routine urinalysis should be done.

(c) Quantitative collection of urine should be made for the first 72 hr for assay of the isotope. Each day's specimen should be put in a separate container. These specimens may be collected in bottles containing 10 ml of dilute nitric acid (approximately 10 ml of concentrated nitric acid per liter of water) for each 24-hr specimen. An additional 10 ml of concentrated nitric acid should be added to the specimen after the collection is complete.

(d) Feces should be collected for the first 72 hr for determination of radioactivity. Each day's specimen should be put in a separate container. These can be collected in round, 1-qt (1-liter) ice-cream containers.

(e) Breath samples should be taken for radon if the accident involves radium.

(f) Arrangement should be made for surveys of the total body gamma radiation with a sensitive measuring device.

(g) Within 72 hr, blood should be taken in 20-ml samples for determination of radioactivity.

(h) The specimens of urine, feces, and blood should be refrigerated and kept until arrangements can be made for analysis at a qualified laboratory. Proper collection and storage of these samples will be of great value to the contaminated persons and also in obtaining further data concerning the metabolism of the isotope involved.

9.4. Special Problems

9.41. *Radium* [6]. The chief hazard of radium is the danger of retention of long-lived alpha-emitting isotopes in the body. The amount of retention depends in part on the salt of radium used. The insolubility of radium sulfate tends to permit less absorption in the body than in the case of the more soluble radium chloride and radium bromide.

Treatment for radium retained within the body should be carried out as follows:

(a) Gastric lavage with 10-percent magnesium sulfate solution should be done as soon as possible.

(b) Daily purging with saline cathartics will tend to promote excretion of radium from the gastroenteric tract, and this type of cathartic will act as a mild stimulant to bile production. Since absorbed radium is excreted to a large degree in the bile, such therapy may be of some value. Administration of magnesium sulfate is suggested, since it will tend to precipitate soluble radium ions in the form of the insoluble sulfate.

(c) If cuts and other skin lesions cannot be adequately decontaminated, surgical excision of the area should be considered.

9.42. *Other isotopes*. Certain other radioactive isotopes are now being used widely both in sealed containers for local irradiation therapy in millicurie quantities and also in teletherapy installations in kilocurie amounts.

(a) *Cobalt-60*. The hazard of spillage from cobalt-60 is relatively small. If Co^{60} sources are not sealed in containers or adequately plated with gold or other coating, some contamination may result from oxidation or corrosion of cobalt. No attempt should be made to remove the protective plating of Co^{60} except by qualified laboratories.

The general procedures to be followed in the event of spillage have been described. Decontamination is best carried out by the use of various complexing agents such as the versenes used with detergents. If Co^{60} is introduced through the skin, areas of local inflammation and possibly sterile abscesses may result. Some Co^{60} will be carried to the liver

and kidneys also. After oral ingestion in rats, Co^{60} is poorly absorbed and is excreted chiefly in the feces. It is removed rapidly from the blood stream via the urine and bile.

(b) *Cesium-137*. This isotope is usually produced as powdered Cs_2SO_4 and then is utilized in a sealed container. The radiation stability of cesium-137 must be carefully evaluated, since certain cesium salts decompose with evolution of oxygen. Therefore, the hazards are similar to those of radium, except that cesium is not a bone-seeker.

Little is known of the metabolism of Cs^{137}. Studies in rats [7] show that oral absorption is 100 percent with 45 percent being deposited in muscle. The half time of elimination from muscle is 15 days. Cesium-137 given parenterally follows the same metabolic pattern. The rate of elimination is very much greater than its rate of radioactive decay.

If Cs^{137} escapes from a sealed container, decontamination can be done with aqueous solutions of detergents or dilute nitric acid.

9.43. *Loss of sources*.

(a) Any loss of a source shall be reported immediately to the radiological safety officer.

(b) All linen, dressings, clothing, and equipment shall be kept within the cubicle or room of a patient until all sources are accounted for.

(c) Each institution should have available one or more portable instruments capable of detecting gamma activity of less than 1 mc at 10 ft. Usually instruments of the ionization-chamber type are less sensitive but more rugged than survey meters using Geiger-Mueller or scintillation counters. Geiger-Mueller survey instruments when used in fields of high radiation intensity may fail completely to respond and thus give inexperienced persons a false sense of security. (For further details see NBS Handbook 51 [4].)

9.5. Decontamination

The following recommendations will facilitate the cleanup of a radioactive isotope especially when it is in the form of a powder.

(a) A traffic-control program should be instituted immediately to minimize trackage.

(b) The following equipment should be assembled: Respirators, coveralls, shoe covers, vacuum cleaner, and steel drums for refuse.

(c) Either inexpensive latex or plastic overshoes can be used. Ordinary brown paper bags may be used as shoe covers in an emergency.

(d) Periodic surveys with appropriate radiation detection instruments should be performed and the readings recorded on an area map.

(e) Vacuum cleaning shall be performed before wet mopping or scrubbing. By vacuum cleaning first, the contamination will be reduced significantly and less radioactive material will become lodged in the flooring. Some type of approved filter for 0.2-micron particles should be put on the exhaust opening of the vacuum cleaner. For example, water vacuum cleaners with such a filter have been efficient. The operator should wear a suitable respirator and helmet. Central vacuum systems shall not be used.

(f) After dry vacuum cleaning, damp mopping with a detergent and chelating agent will help to remove radioactive contamination.

9.6. Disposal of Radioactive Materials

9.61. It is not practicable in this Handbook to provide detailed information concerning the disposal of radioactive materials. Such information can be obtained from current reports [8, 9, 10, 11, 12] or from the supplier of the particular source.

10. References

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[2] M. Brucer, Teletherapy design problems, Radiology **62**, 91 (1954).

[3] N. Irving Sax, Handbook of dangerous materials, p. 236 (Reinhold Publishing Corp., New York, N. Y., 1951).

[4] National Bureau of Standards Handbook 51, Radiological monitoring methods and instruments.

[5] National Bureau of Standards Handbook 48, Control and removal of radioactive contamination in laboratories.

[6] Eugene L. Saenger, et al., Emergency measures and precautions in radium accidents, J. Am. Med. Assoc. **149**, 813 (1952).

[7] J. G. Hamilton, Metabolism of fission products and the heaviest elements, Radiology **49**, 325 (1947).

[8] Special waste disposal service, Isotopics **2**, No. 3, p. 8 (1952). Obtainable from the Superintendent of Documents, Government Printing Office, Washington 25, D. C., 35 cents.

[9] G. W. Morgan, Decontamination and disposal of radioactive wastes. Health physics seminar for insurance company representatives, TID-388, February 1950. Obtainable from the Office of Technical Services, Department of Commerce, Washington 25, D. C., 40 cents.

[10] National Bureau of Standards Handbook 49, Recommendations for waste disposal of phosphorus-32 and iodine-131 for medical users.

[11] National Bureau of Standards Handbook 53, Recommendations for the disposal of carbon-14 wastes.
[12] National Bureau of Standards Handbook 58, Radioactive- waste disposal in the ocean.
[13] C. B. Braestrup, "Radiation: protection; radium," chapter in Medical Physics, vol. II, 1950 (ed. by O. Glasser), page 774.
[14] R. J. Kennedy, H. O. Wyckoff, and W. A. Snyder, Concrete as a protective barrier for gamma rays from cobalt-60, J. Research NBS 44, 157 (1950) RP2066.
[15] National Bureau of Standards Handbook 52, Maximum permissible amounts of radioisotopes in the human body and maximum permissible concentrations in air and water.
[16] National Bureau of Standards Handbook 42, Safe handling of radioactive isotopes.

Appendix A. Encapsulation of Sources

A.1. General

This section is a guide for the encapsulation of sources so as to provide assurance against capsule failure. The hazards associated with such failure are discussed in section 9.

A.2. Capsules

A.21. The choice of capsule material depends upon the type of activity, the energy of the important radiations, and the requirements of special applications. For a given thickness, wall absorption of gamma radiation is nearly a direct function of the density of the material. Dense capsule materials may appreciably decrease the available radiation and change it in character by filtering out the less energetic components.

A.22. The noble metals are extensively used for medical source capsules because of clinical consideration. Although noble metals have a high density, they are not always as structurally desirable as some base metals for this purpose.

A.23. Aluminum, stainless steels, monel, brass, and other base-metal alloys may be more suitable for encapsulation of nonmedical sources because of a more advantageous density-to-structural-strength relationship. The ferrous metals have the additional advantage of lending themselves to remote handling by magnetic devices.

A.24. Glass capsules should be avoided whenever possible. The danger of fracture is great and in the case of alpha emitters there is a possibility of failure through devitrification and the development of crazing cracks due to long-continued alpha bombardment. Sealing the glass into an enveloping metal capsule diminishes these hazards.

A.25. Whenever size permits, capsules shall be clearly and permanently marked, and be readily identifiable from a considerable distance as to their content. When sizes and shapes are not adequate, other means of identification should be employed, such as plating, enameling, or electrolytic etching with different colors.

A.26. Complete information regarding construction of the capsule and seal shall be provided the buyer or user by the manufacturer.

A.3. Sealing

A.31. All capsules shall be permanently and hermetically sealed and shall be free of significant contamination.

A.32. Seals shall be complete and have approximately the same strength as the remainder of the capsule. Any type of seal should be tested under a pressure differential of several atmospheres before being specified. Aside from complete failures, partial failures of the capsule seals may result in freeing radioactive materials from those preparations in which a gas pressure accumulates.

A.33. Flame-sealed glass tubes must be carefully annealed to relieve residual stresses.

A.4. Additional Considerations for Radium and Radon Preparations

A.41. Radium and radon gamma-ray sources shall be made of suitable metal of adequate strength, preferably with a wall thickness of not less than 0.5 mm of platinum or its equivalent to absorb primary beta radiation.

A.42. Radium salts shall be thoroughly dehydrated before encapsulation. The decomposition of water in any form by alpha radiation increases the danger of capsule rupture due to the buildup of gas pressure.

A.43. The manufacturer shall obtain data as to the uniformity of distribution and amount of the activity and shall provide this information to the buyer or user together with the identification of the capsule, of the metal employed for the capsule and its wall thickness, and of the type and purity of the radium salt used.

A.44. Whenever feasible, old glass tubes containing radium salts should be reencapsulated or sealed within an additional metal envelope. Such preparations should be recalibrated

Appendix B. Shipping Rules

B. 1. *Interstate Commerce Commission regulations.* The essentials of the ICC requirements pertaining to labeled [13] express packages are as follows:

(a) The package shall not contain more than 2,000 mc of radium or 2,700 mc of Co^{60} and Cs^{137}.

(b) It shall be packed and shielded so that the surface dose-rate does not exceed 200 mr/hr (gamma).

(c) The dose rate at 1 m distance from the source shall not exceed 10 mr/hr (gamma).

(d) There shall be no surface contamination.

(e) Boxes shall be ICC Specification (15A or 15B wooden or 12B fiberboard), with the smallest dimension 4 in.

Certain packages are exempt from labels, but in general this does not apply to sources of the type covered by this Handbook.

B. 2. *Post Office Department regulations.* For all practical purposes, the transportation by mail of sources of the type covered by this Handbook is prohibited by the Postal Regulations.

B. 3. *Civil Aeronautics Board regulations.* In addition to the general provisions of the ICC regulations, the CAB requires an additional label bearing the following statement to be affixed to each package:

> This is to certify that the contents of this package are properly described by name and are packed and marked and are in proper condition for transportation according to the regulations prescribed by the Interstate Commerce Commission and the Civil Aeronautics Board.

For shipment on passenger-carrying aircraft, add the following:

> This shipment is within the limitations prescribed for *passenger-carrying aircraft.*

As airlines are not required to accept shipments, even if they meet the CAB regulations, some lines refuse all shipments of radioactive materials.

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[13] Labels refer to special Class-D Poison labels, obtainable from the Bureau of Explosives, Association of American Railroads, 30 Vesey Street, New York 7, N. Y. Complete ICC Regulations are obtainable from the same source (current price $3.50).

Appendix C. Barrier Design Data and Computations

C. 1. Figures 5, 6, and 7 give the transmission of gamma rays in concrete, iron, and lead.

C. 2. Table 2 shows the fraction of time that people may be in the vicinity of a source.

C. 3. Table 4 has been computed for values of *WT* equal to 80,000 by the method outlined in section 2.34. Half-value layers are also listed for each of the radiations in each of the absorbers.

C. 4. Table 5 shows the barrier requirements for scattered radiation from teletherapy units. It is assumed that the scattered beam comes from a small area not less than 50 cm from the target, and that the useful beam gives 80,000 r/week at 1 m.

C. 5. Table 6 shows the number of half-value layers that must be added or subtracted from tabular values of tables 4 and 5 for other values of *WT*. If, for instance, *WT* is 40,000 in a particular design, 1 HVL must be subtracted from the values of tables 4 and 5.

C. 6. Curves of figures 10 through 18 show the protection requirements for small sources when people are exposed for 48 hr/week. If, for instance, a cobalt-60 source is to be used at a distance of 10 m from occupied space with an intervening wall of 6 in. of solid concrete (specific gravity 147 lb/ft^3), the largest source that could safely be used is one giving 2.1 rhm.

C. 7. Table 7 gives the relation between distance and millicurie-hours for an exposure of 0.3 r from an unshielded source.

C. 8. Tables 8, 9, and 10 show lead thicknesses for small sources at different distances and for different exposure times.

Submitted for the National Committee on Radiation Protection.

Lauriston S. Taylor, *Chairman.*

Washington, March 31, 1954.

TABLE 1. *Radiations emitted by certain isotopes* [a]

Isotope	Radiation		Range	
	Type	Energy	Air	Aluminum
Radium series:		*Mev*	*cm*	*mm*
Radium-226	Alpha	4.79, 4.61	3.1	--------
	Gamma	0.18	----	--------
Radon-222	Alpha	5.49	3.9	--------
Polonium-218 (radium A)	Alpha	6.0	4.5	--------
Lead-214 (radium B)	Beta	0.65	----	0.9
	Gamma	0.24 to 0.35	----	--------
Bismuth-214 (radium C)	Beta	1.65, 3.15	----	5.9
	Gamma	0.42 to 2.4	----	--------
	Alpha	5.5	3.9	--------
Polonium-214 (radium C′)	Alpha	7.68 to 10.5	6.6	--------
Thallium-210 (radium C″)	Beta	1.8	----	3.1
	Gamma	approx. 5	----	--------
Lead-210 (radium D)	Beta	0.029	----	0.006
	Gamma	0.007 to 0.047	----	--------
Bismuth-210 (radium E)	Beta	1.17	----	1.9
Polonium-210 (radium F)	Alpha	5.3	3.6	--------
Cobalt-60	Beta	0.31	----	0.31
	Gamma	1.17, 1.33	----	--------
Cesium-137	Beta	0.51, 1.2	----	2.0
	Gamma	0.661	----	--------

[a] Nuclear Data, National Bureau of Standards Circular 499.

TABLE 2. *Occupancy factors.*

For use as a guide in planning shielding where complete occupancy data are not available.

Full occupancy ($T=1$)
Control space, residences, wards, office workrooms, darkrooms, corridors and waiting space large enough to hold desks, rests rooms used by the radiologic staff and others routinely exposed to radiation, play areas.
Partial occupancy ($T=1/4$)
Corridors in X-ray departments too narrow for future desk space, rest rooms not used by radiologic personnel, parking lots, utility rooms.
Occasional occupancy ($T=1/16$)
Stairways, automatic elevators, streets, closets too small for future workrooms, toilets not used by radiologic personnel.

TABLE 3. *Possible teletherapy sources.*

Although the present scope of this Handbook is limited to radium, cobalt-60, and cesium-137; other isotopes are included in this table, since they are currently under investigation for teletherapy. *Most of these figures are based on incomplete but the best available data.* The basic problems of protection are common to all.

Isotope	Half-life	Gamma energy	Practical clinical form	Production	Highest practical-volume specific activity	Specific gamma exposure rate
		Mev			[e] *Curies/cm³*	*r/curie-hr at 1 m* [d]
Radium-226	1,620y	0.2 to 2.2	Sulfate	Natural	4	[a] 0.84
Cesium-137	33y	0.661	Sulfate	Fission	100	0.39
Europium-152-154	12.4y	[a] 1.0	Oxide	Nuclear reactor	5,000	0.7
Cobalt-60	5.3y	1.17, 1.33	Metal	do	1,000	1.35
Cesium-134	2.3y	0.5 to 1.3	Sulfate	do	1,000	1.2
Cerium-144	275d	[b] 0.6, 2.6	Oxide	Fission	2,000	0.2
Silver-110	270d	0.6 to 1.5	Metal	Nuclear reactor	250	1.4
Thulium-170	127d	0.08	Oxide	do	500	0.01
Tantalum-182	117d	0.04 to 1.2	Metal	do	1,500	0.6
Scandium-46	85d	0.9, 1.1	Oxide	do	500	1.1
Terbium-160	74d	0.1 to 1.1	Chloride	do	50	0.3
Iridium-192	70d	0.1 to 0.6	Metal	do	1,000	0.3

[a] Following filtration with 3.0 mm of lead, 83 percent of total radiation appears to be from four high-energy photons averaging 1.08 Mev.
[b] Gamma activity from 17-min praseodymium daughter; energy levels are doubtful.
[c] One year irradiation in 5×10^{13} n/cm²/sec, 1 year after removal from reactor, ideal geometry, for neutron reactions.
[d] Assuming that gamma absorption in the source is negligible.
[e] *This assumes the source is sealed within a 0.50-mm-thick platinum capsule.*

Table 4. *Primary-protective-barrier requirements for teletherapy*

Work load equal to 80,000 r/week at 1 m

Source-to-occupied-space distance		Radium			Cobalt-60			Cesium-137		
		Concrete	Steel	Lead	Concrete	Steel	Lead	Concrete	Steel	Lead
m	*ft*	*in.*	*in.*	*cm*	*in.*	*in.*	*cm*	*in.*	*in.*	*cm*
3	--	42.5	13.4	23.1	38	12.6	19.2	30	10.9	9.6
	10	42	13.4	23.1	38	12.6	19.2	30	10.9	9.5
4	--	40	12.6	21.6	36	11.8	18.2	29	9.3	9.0
	15	39	12.2	20.9	35	11.6	17.6	28	9.1	8.8
5	--	38	12.0	20.4	34.5	11.4	17.4	27.5	8.9	8.6
	20	36.5	11.4	19.3	33	10.8	16.6	26	8.5	8.2
7	--	35.5	11.0	18.6	32	10.4	16.1	25.5	8.3	7.9
	25	34.5	10.8	18.1	31.5	10.2	15.7	25	8.2	7.8
8	--	34.5	10.8	17.9	31	10.2	15.6	25	7.9	7.7
	30	33.5	10.4	17.2	30.5	9.8	15.1	23	7.8	7.5
10	--	32.5	10.2	16.8	29.5	9.6	14.8	22.5	7.6	7.3
Approximate HVL thickness		2.6	0.9	1.3	2.5	0.9	1.2	1.9	0.65	0.6

Table 5. *Protective barrier for scattered radiation in teletherapy* [a]

Work load equal to 80,000 r/week at 1 m

Scatterer-to-occupied-space distance		Radium and cobalt-60		Cesium-137	
		Concrete	Lead	Concrete	Lead
m	*ft*	*in.*	*mm*	*in.*	*mm*
3	------	11.9	18.3	9.8	8.8
	10	10.8	18.1	9.7	8.7
4	------	9.6	15.0	8.6	7.3
	15	9.0	13.6	8.0	6.6
5	------	8.6	12.9	7.6	6.3
	20	7.8	11.0	6.9	5.1
7	------	7.1	10.5	6.3	4.6
	25	6.8	8.6	6.0	4.2
8	------	6.5	8.3	5.7	4.0
	30	5.9	7.3	5.1	3.3
10	------	5.5	6.9	4.8	2.9
Approximate HVL thickness		1.6	[b] 3.3	1.4	[b] 1.9

[a] Shielding required to reduce the scattered radiation to 0.3 r/week for a work load of 80,000 r/week at 1 m and occupancy factor of 1. See table 6 for the number of half-value layers to be subtracted for other work loads. The barrier for leakage radiation will depend upon the leakage permitted by the source housing.

[b] These values are only for estimating purposes, since they vary considerably over the range of attenuations of interest.

TABLE 6. *Corrections to tables 4 and 5 for other work loads*

Work load (r/week at 1 m)	Number of HVL to be added or subtracted	Work load (r/week at 1 m)	Number of HVL to be added or subtracted
2,500	−5.0	40,000	−1.0
5,000	−4.0	80,000	0
10,000	−3.0	160,000	+1.0
20,000	−2.0		

TABLE 7. *Relation between distance and millicurie-hours for an exposure of 0.3 r from an unshielded source*

Millicurie-hours	Distance to source		
	Radium	Cobalt-60	Cesium-137
	ft	*ft*	*ft*
10	0.5	0.7	0.4
30	1.0	1.2	0.6
100	1.8	2.2	1.2
300	3.0	3.8	2.1
1,000	5.5	7.0	3.7
3,000	9.5	12	6.5
10,000	18	22	12

TABLE 8. *Protection requirements for radium in centimeters of lead*

Milligrams of radium	Thicknesses of lead required at a distance of—		
	30 cm	1 m	2 m
	48 hr/week		
	cm	*cm*	*cm*
25	6.6	1.9	0
50	8.1	3.3	0.7
75	9.0	4.0	1.3
100	9.6	4.6	1.9
200	11.1	6.0	3.3
	12 hr/week		
25	3.8	0	0
50	5.2	0.7	0
75	6.1	1.3	0
100	6.6	1.9	0
200	8.1	3.3	0.7
	6 hr/week		
25	2.5	0	0
50	3.8	0	0
75	4.6	0.3	0
100	5.2	0.7	0
200	6.6	1.9	0

TABLE 9. *Protection requirements for cobalt-60 in centimeters of lead*

Cobalt (rhm)	Thicknesses of lead required at a distance of—		
	30 cm	1 m	2 m
48 hr/week			
	cm	*cm*	*cm*
0.1	9.4	5.5	3.0
0.3	11.3	7.5	5.0
1.0	13.4	9.5	7.1
3.0	15.4	11.4	9.0
10.0	17.7	13.6	11.1
12 hr/week			
0.1	7.0	3.0	0.6
0.3	8.9	5.0	2.6
1.0	11.0	7.2	4.7
3.0	13.0	9.1	6.6
10.0	15.1	11.1	8.6
6 hr/week			
0.1	5.8	1.8	0
0.3	7.7	3.9	1.3
1.0	9.7	5.9	3.5
3.0	11.7	7.8	5.4
10.0	13.9	10.0	7.5

TABLE 10. *Protection requirements for cesium-137 in centimeters of lead*

Cesium (rhm)	Thicknesses of lead required at a distance of— 30 cm	1 m	2 m
48 hr/week			
	cm	*cm*	*cm*
0.01	2.7	0.7	0
0.03	3.7	1.65	0.35
0.1	4.85	2.8	1.5
0.3	5.9	3.8	2.5
1.0	7.0	4.95	3.6
12 hr/week			
0.01	1.4	0	0
0.03	2.4	0.35	0
0.1	3.55	1.5	0.15
0.3	4.6	2.55	1.2
1.0	5.75	3.65	2.35
6 hr/week			
0.01	0.8	0	0
0.03	1.75	0	0
0.1	2.95	0.9	0
0.3	3.95	1.9	0.55
1.0	5.05	3.0	1.7

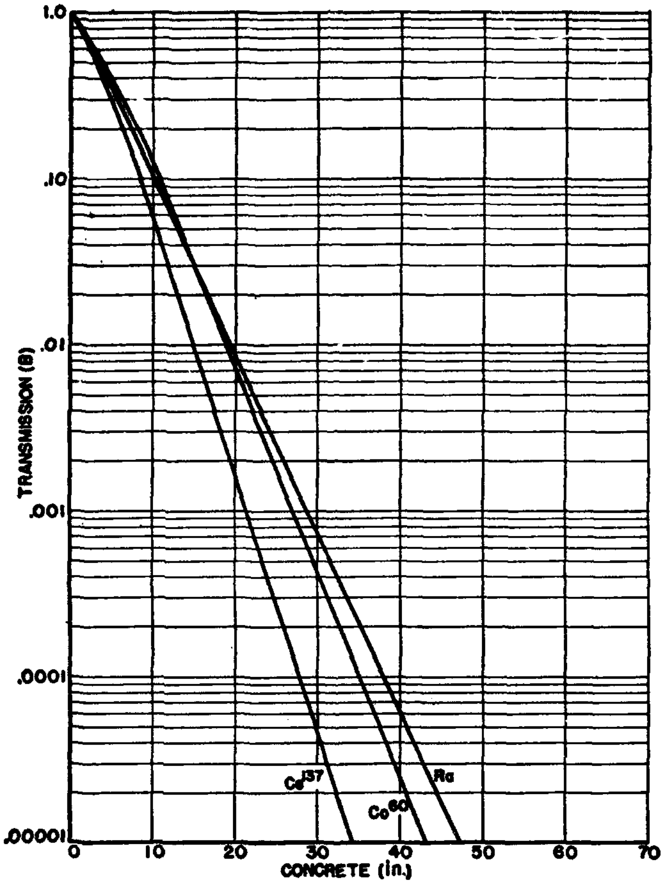

Figure 5. *Transmission through concrete (specific gravity 147 lb/ft³) of gamma rays from radium, cobalt-60, and cesium-137.*

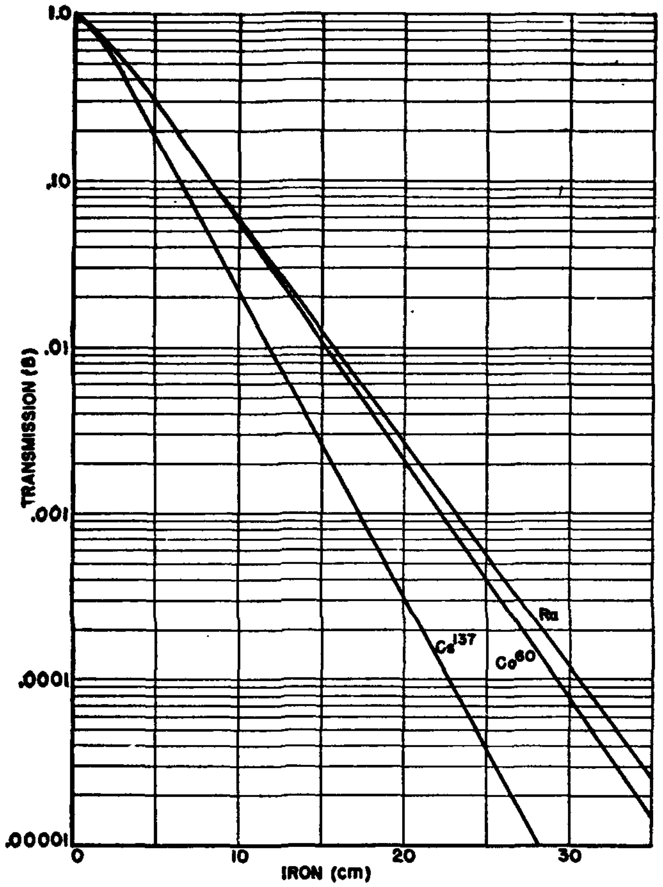

Figure 6. *Transmission through iron of gamma rays from radium, cobalt-60, and cesium-137.*

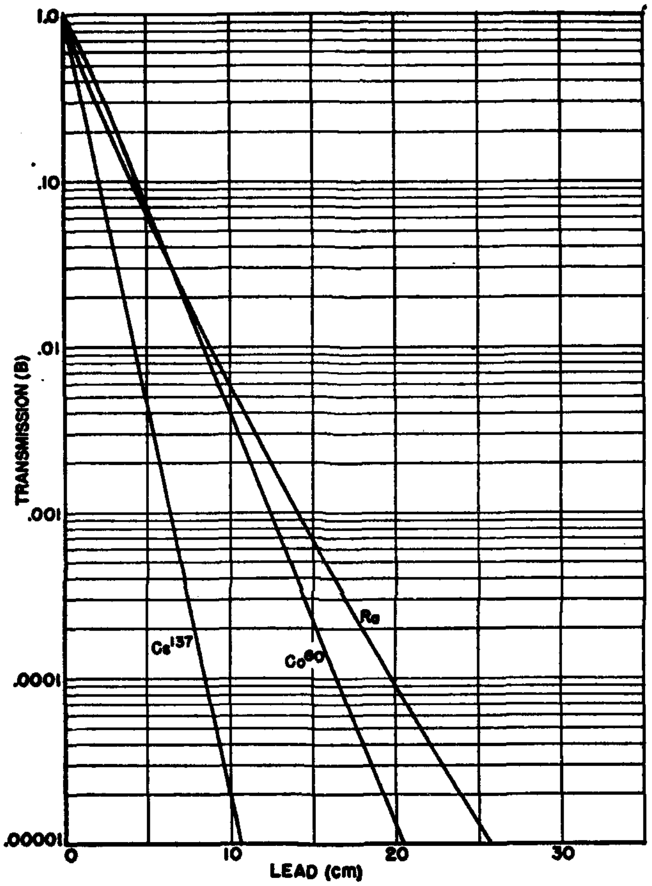

FIGURE 7. *Transmission through lead of gamma rays from radium, cobalt-60, and cesium-137.*

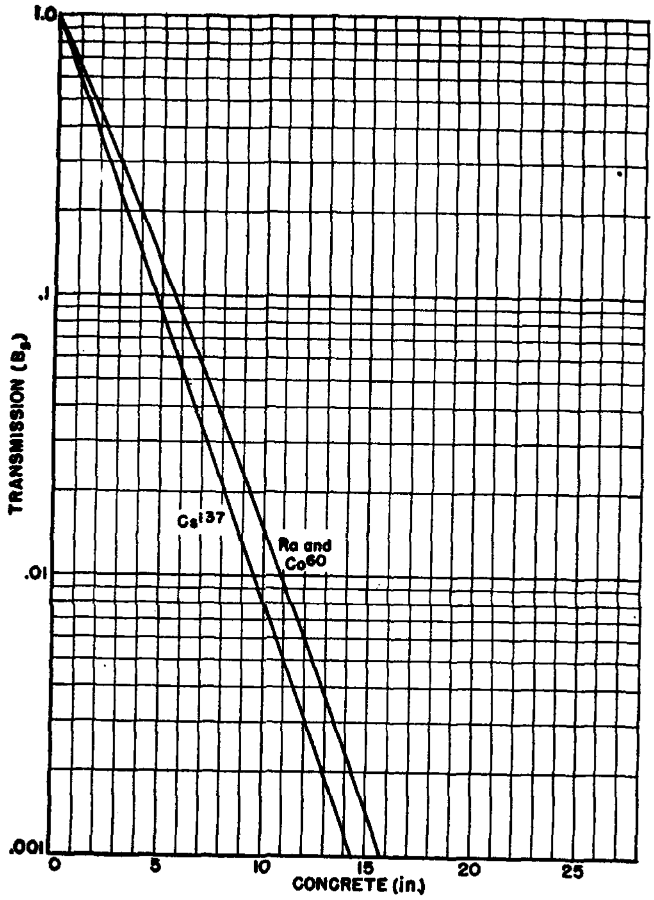

Figure 8. *Transmission through concrete (specific gravity 147 lb/ft³) of 90-degree-scattered gamma rays from radium, cobalt-60, and cesium-137.*

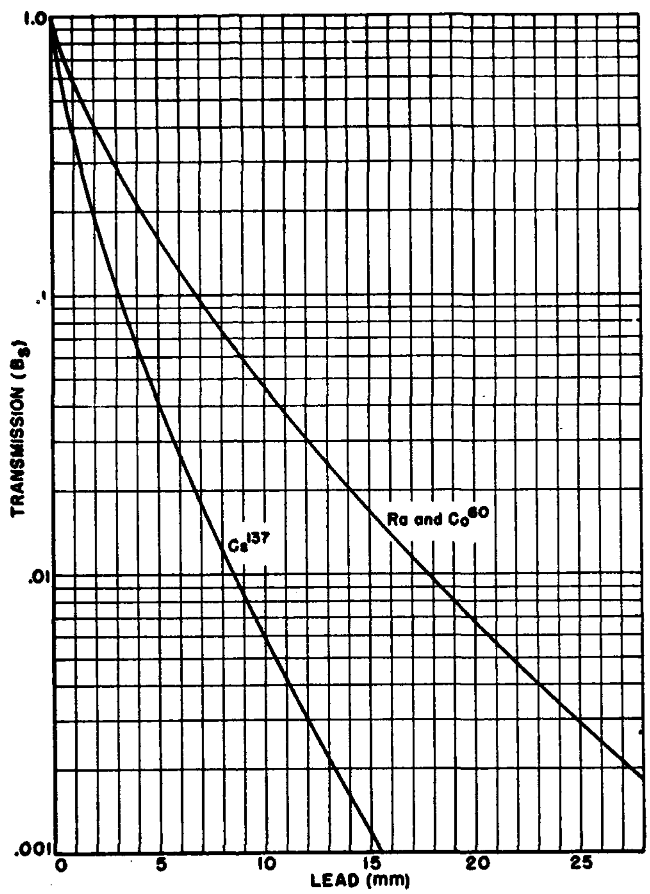

FIGURE 9. *Transmission through lead of 90-degree-scattered gamma rays from radium, cobalt-60, and cesium-137.*

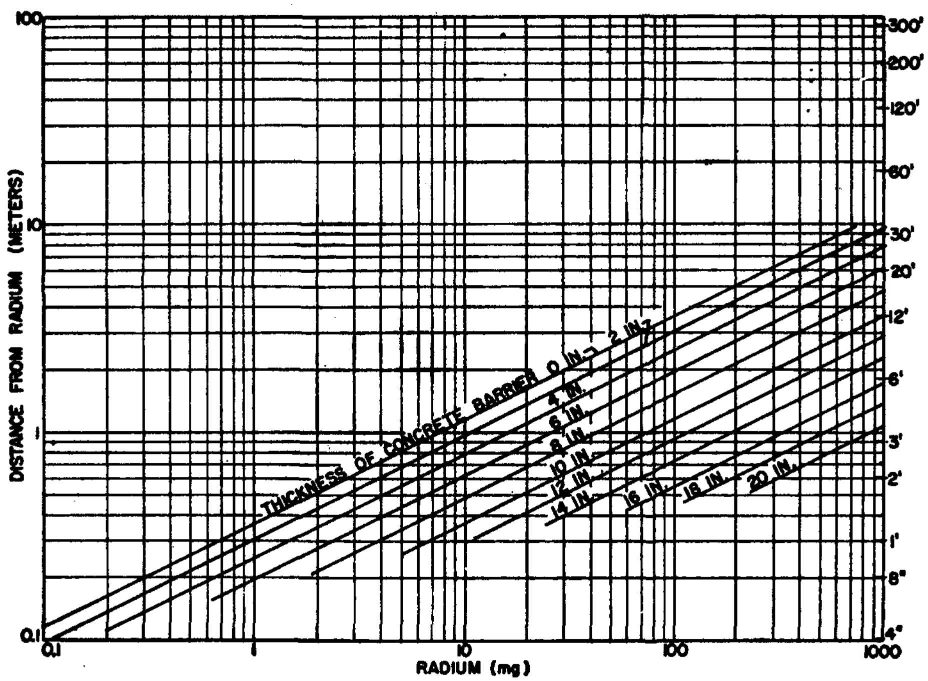

FIGURE 10. *Relation between curiage, distance, and shielding for 48 hr/week occupancy: radium behind concrete barrier.*

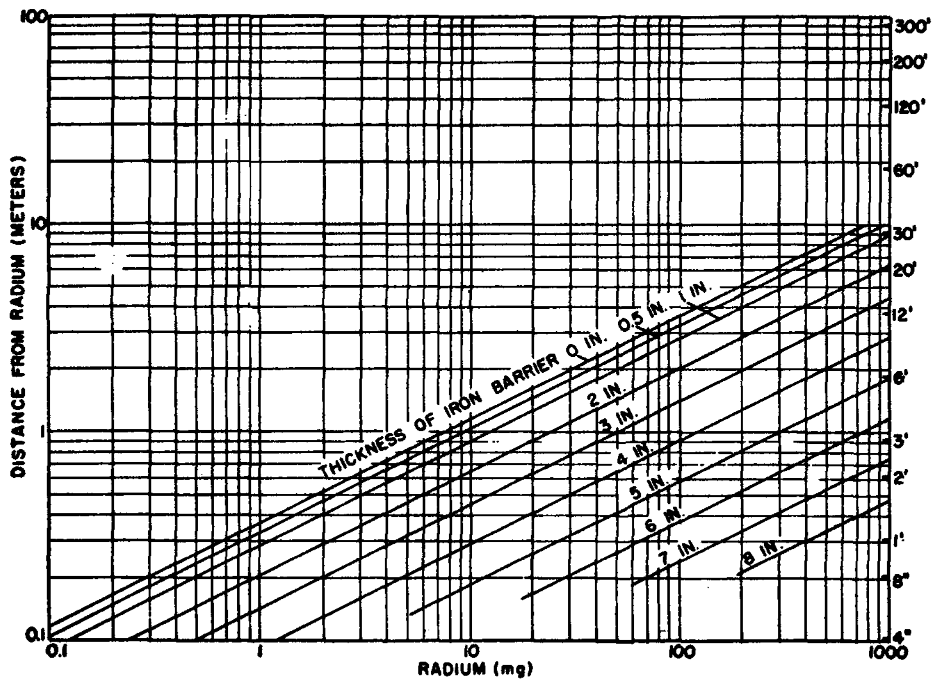

FIGURE 11.
Relation between curiage, distance, and shielding for 48 hr/week occupancy: radium behind iron barrier.

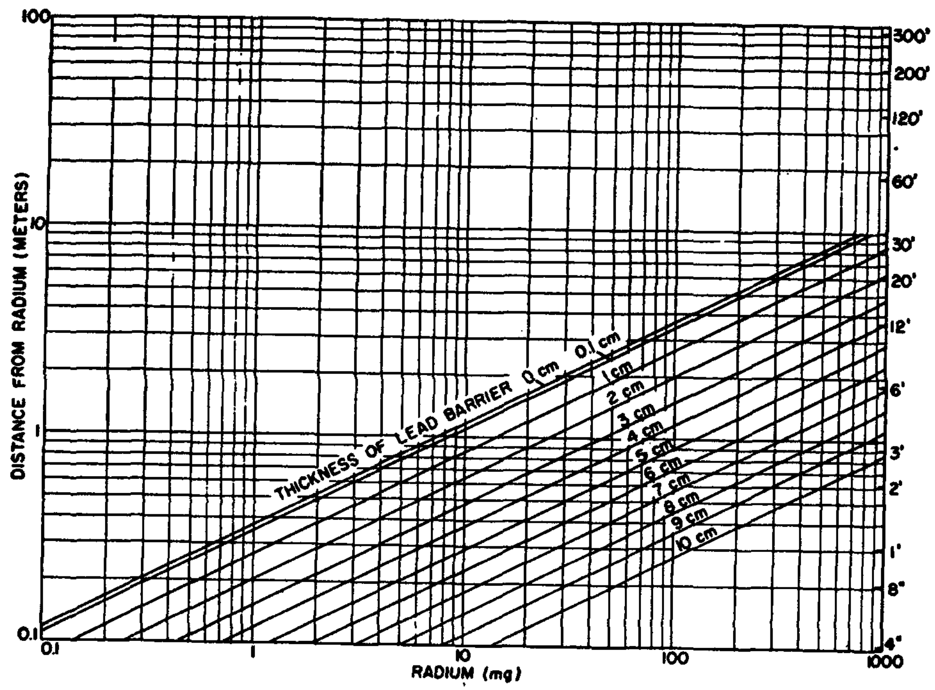

Figure 12.
Relation between curiage, distance, and shielding for 48 hr/week occupancy: radium behind lead barrier.

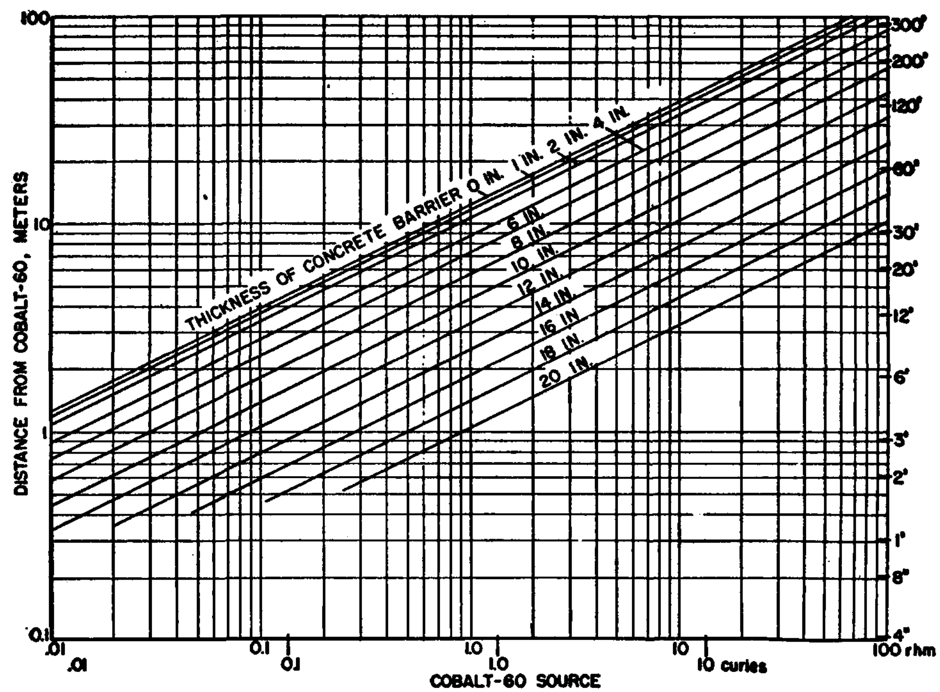

Figure 13. *Relation between curiage, distance, and shielding for 48 hr/week occupancy: cobalt-60 behind concrete barrier.*

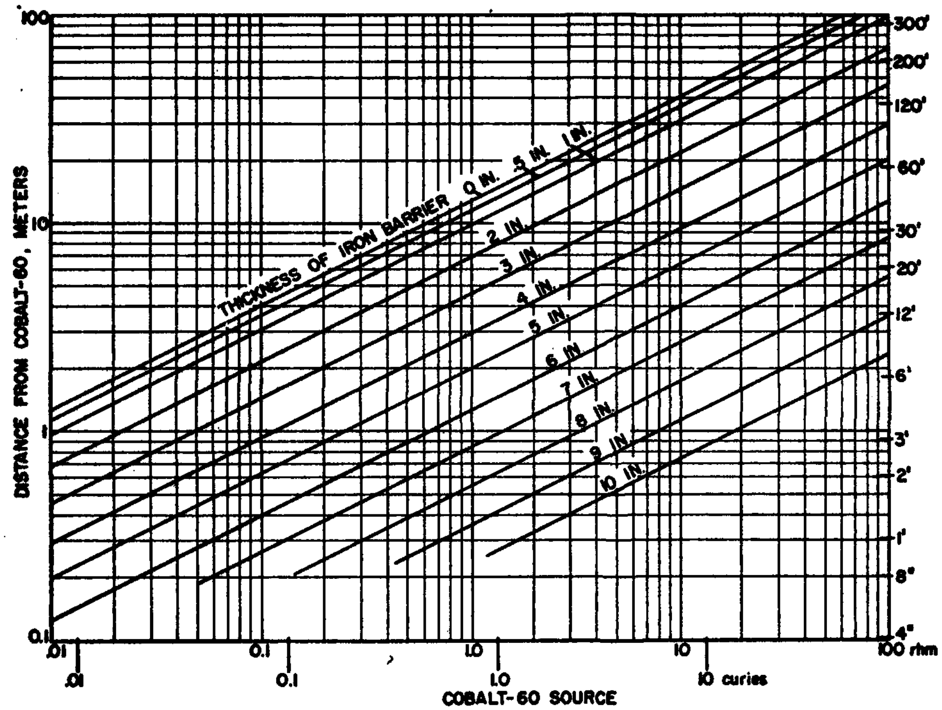

Figure 14. *Relation between curiage, distance, and shielding for 48 hr/week occupancy: cobalt-60 behind iron barrier.*

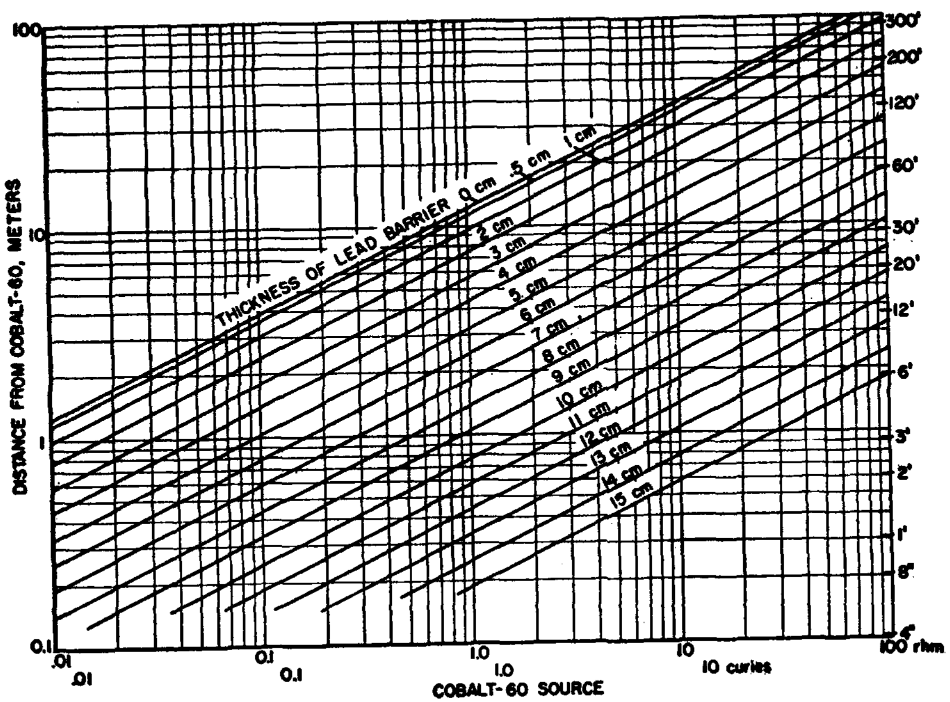

Figure 15.
Relation between curiage, distance, and shielding for 48 hr/week occupancy: cobalt-60 behind lead barrier.

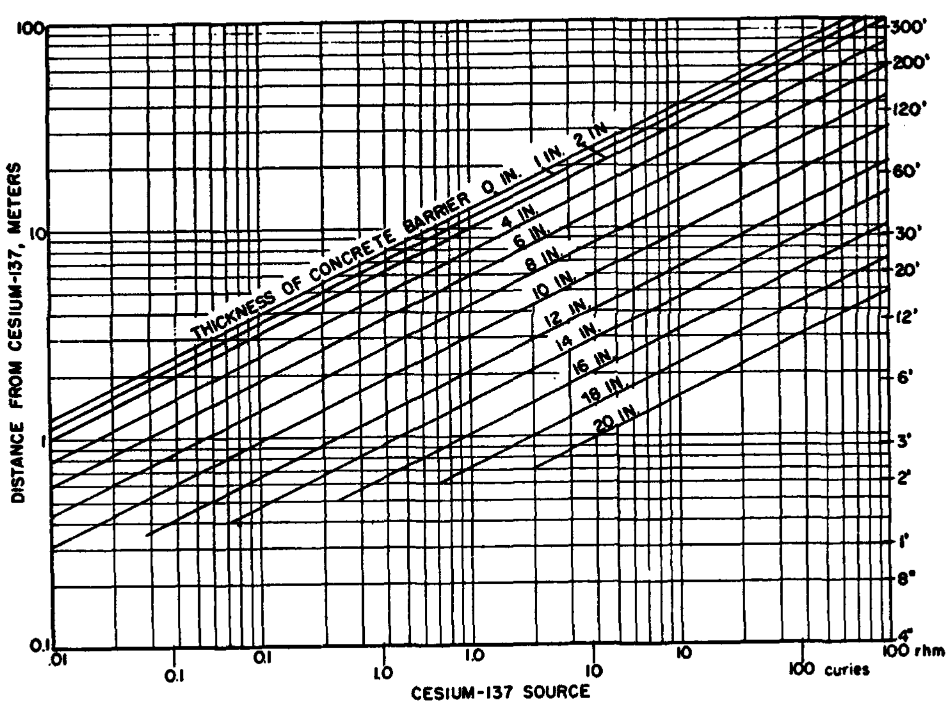

Figure 16.
Relation between curiage, distance, and shielding for 48 hr/week occupancy: cesium-137 behind concrete barrier.

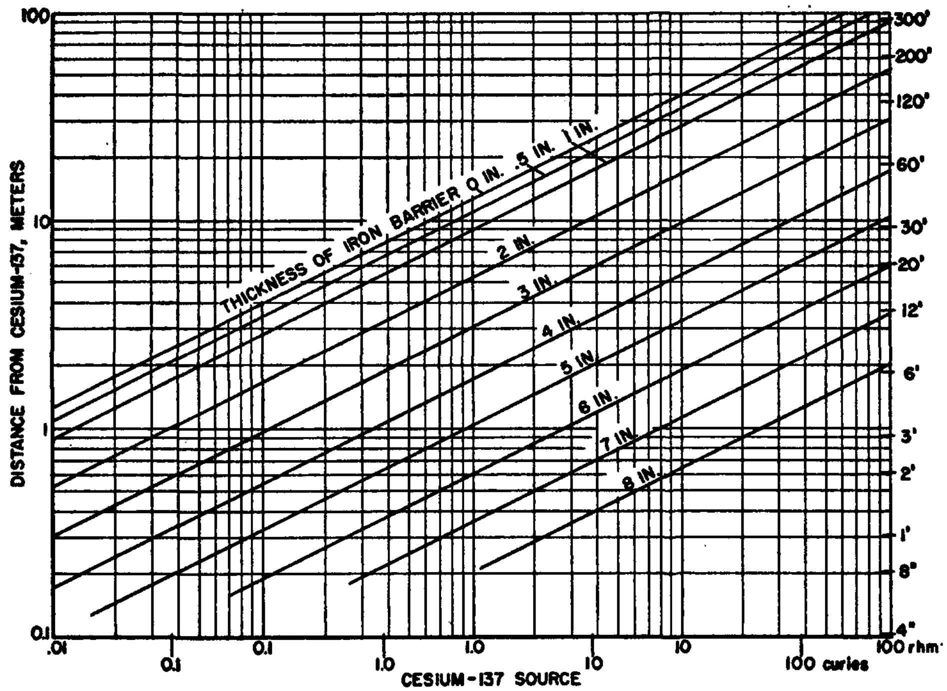

FIGURE 17.
Relation between curiage, distance, and shielding for 48 hr/week occupancy: cesium-137 behind iron barrier.

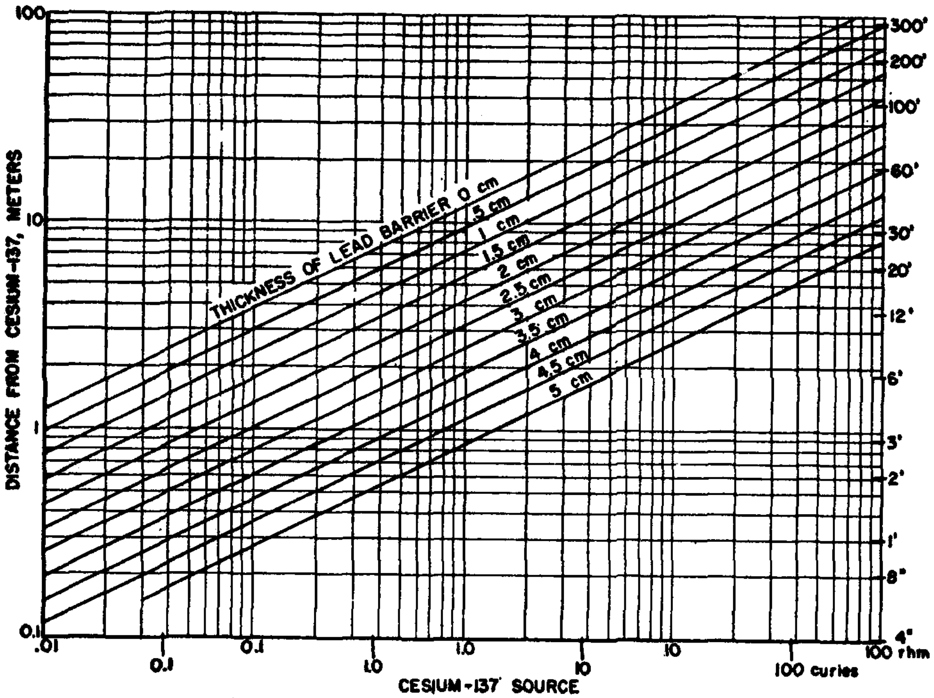

Figure 18.
Relation between curiage, distance, and shielding for 48 hr/week occupancy: cesium-137 behind lead barrier.

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